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THE ARTIFICIAL ILLUMINATION OF SEEDLINGS

By W. J. C. LAWRENCE and A. CALVERT
John Innes Horticultural Institution, Hertford

INVESTIGATIONS on the design of glasshouses (Lawrence, 1950) showed that, in Britain, light was the limiting factor for seedling growth during the six winter months. Given a moderately high standard of cultivation, higher temperatures, more fertilizer, more water, etc., cannot markedly improve growth and yields unless, first, the amount of light is increased.

One way of getting more light into the glasshouse in winter is to improve the design of the house but, even when the best design is used, there is still a great deficiency of light. The only possible means, therefore, of improving plant growth in winter is by supplementing daylight with artificial light and, if this could be done satisfactorily, then the plant breeder might be able to raise two or more generations a year and the commercial grower produce earlier crops.

Various workers have used artificial light to secure photoperiodic effects, e.g. advanced or delayed flowering. For this, relatively low intensities, of the order of 5-50 foot-candles, are adequate and the problem of finding suitable cheap sources of light is easily solved. Precisely the converse applies where improved seedling growth is desired. Few workers have made thorough investigations; moderately high intensities are required and the problem of light sources is complex. This paper considers ways of solving the problem.

MATERIALS AND METHODS.

Cultures.

Tomato (*Lycopersicon esculentum*) has been used as the main subject for these experiments. It not only has the dual advantage of responding well to light and being easy to measure for size but is of great economic importance. In order to increase the scope of the experiments, cucumber (*Cucumis sativus*) and lettuce (*Lactuca sativa*) were later included as test subjects.

Standardized methods were adopted throughout the experiments. All plants were raised in John Innes composts. The seedlings were pricked out into 3- or $3\frac{1}{2}$-inch pots as soon as their cotyledons had fully expanded, i.e. within two or three days of germination. The seedlings were then placed on the glasshouse bench in replicated rows and illuminated for a given number of hours for about twenty consecutive nights. The plants were then cut off just below cotyledon level and weighed fresh.

Dry weight was ascertained in two of the tomato experiments to check the reliability of fresh weight as a criterion of rate of plant development. Twenty-six observations were made, involving 237 plants. The very high correlation $r = +0{\cdot}996$ found between fresh and dry weights indicates that for the purpose of the present experiments, fresh weight is a quite adequate criterion of growth.

Measurement of light intensity.

A selenium photo-electric cell (Weston Lightometer) was used for measuring light intensity (Fig. 5). Advantage was taken of the fall off in light intensity towards

the edges of an illuminated area to measure the growth of plants exposed to different intensities of light from the same source and so determine the relation of growth to intensity for that particular light source. All the figures given for " light intensity " in the present paper represent photometer readings with the Weston cell expressed as foot-candles (f.c.). While photometric units of this type may legitimately be used in comparing different intensities from the same type of lamp source, they cannot be used directly in comparing light sources differing in spectral composition. A first approximation to a scale for comparing different light sources may, however, be achieved, as we shall see, by the use of correction factors appropriate to each type of light source (p. 161).

Lamps.

The types of lamps and reflectors used are described below.

(1) *Fluorescent.* (*a*) Type MCF/U, five feet long, 80 watt Daylight tubular lamps, arranged horizontally and spaced 6 inch centres ; reflectors of sheet aluminium, painted matt white. In some experiments, the reflector consisted of a flat sheet mounted about 1 inch above the lamps ; in others, a separate trough-shaped reflector was used for each lamp. (*b*) Experimental lamps as above but giving peak radiation in the red and blue (see Fig. 5).

(2) *Dual* (Mercury-tungsten). Type MAT/V, 500 w. vertical lamp, mounted in a truncated pyramid-shaped reflector such that direct light from the tube was confined to, and just covered, the $3\frac{1}{2}$-ft.-wide bench on which the plants were stood.

(3) *Mercury.* Type MA/H, 400 w. horizontal high pressure mercury vapour (H.P.M.V.) lamps, each mounted in an aluminium trough-shaped reflector, throwing light on the bench as in the Dual lamp. Vertical type MA/V lamps were used in one experiment with reflectors as for the Dual lamps.

(4) *Neon.* Low-pressure, floodlight type, 400 w., 46 inches long, mounted in a trough-shaped reflector with sides extended to confine light to the bench.

(5) *Sodium.* Type SO/H, 140 w. horizontal lamp, with reflector similar to the horizontal mercury lamp.

TABLE I.

Experiment	Tomato variety	Sown	Pricked out	No. of plants	Illuminated	
					Approx. hours per day	Period
1	Potentate	3 Nov., 1947	11 Nov.	(i) 356 (ii) 456	4.30 p.m.-10.30 p.m. 4.30 p.m.- 1.30 a.m.	11 Nov. to 1 Dec.
2	,,	4 Dec., 1947	12 Dec.	(i) 363 (ii) 361	4.0 p.m.-10.0 p.m. 4.0 p.m.- 2.0 a.m.	12 Dec. to 1 Jan.
3	,,	1 Jan., 1948	8 Jan.	(i) 236 (ii) 175*	4.0 p.m.-2.0 a.m. 4.0 p.m.-2.0 a.m.	8 Jan. to 29 Jan.
4	Potentate Ailsa Craig	20 Oct., 1948	27 Oct.	341	5.0 p.m.-10.0 p.m.	28 Oct. to 16 Nov.
5	,,	,,	,,	421	10.0 p.m.-3.0 a.m.	28 Oct. to 16 Nov.

* Red-blue fluorescent lamps, see p. 162.

EXPERIMENTAL.

The experiments are described under five headings, namely, (1) intensity and duration of illumination, (2) the duration of the dark period, (3) spectral composition, (4) temperature, and (5) seedling illumination and crop yield.

Intensity and duration of illumination.

In Experiments 1-5 daylight fluorescent lamps were used, a group of 7 lamps in Experiments 1-3 and of 14 in Experiments 4-5. The lamps were mounted on

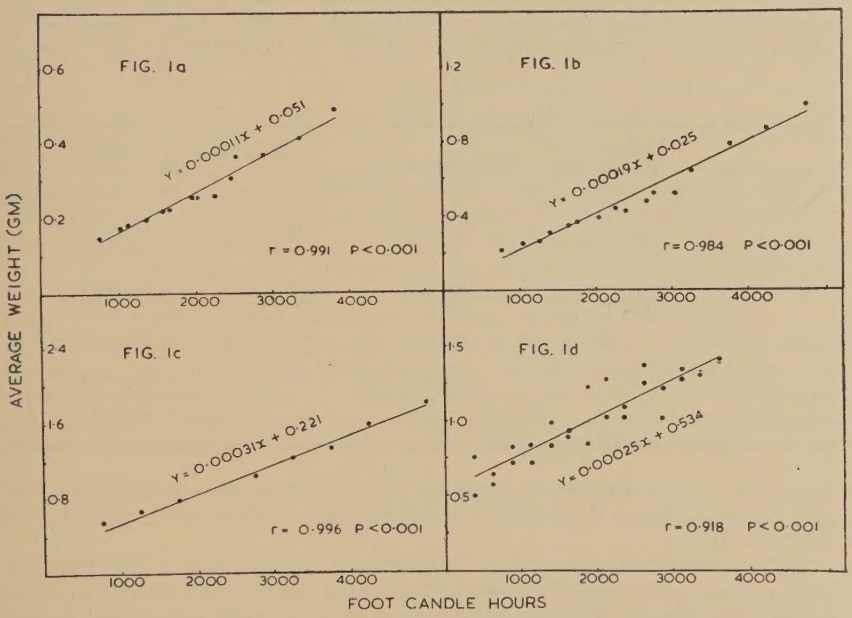

FIG. 1.

Tomato. Showing the relation between seedling weight and foot-candle-hours per day supplementary artificial light. (Experiments 1-4.)

rails which permitted them to be moved right away from the plants during the day. All plants were weighed separately. Other details are given in Table I. The results are set out in Table II which gives the range of seedling fresh weights achieved by light treatment, and Figs. 1a-1d which show the relation between light quantity (foot-candle-hours) and fresh weight for Experiments 1-4. The individual plant weights were arranged for this purpose in grouping intervals of 50 f.c. It will be seen that artificial illumination has produced large increases in weight over the controls and that, over the range used, the increase is approximately proportional to the quantity (foot-candle-hours) of illumination supplied.

Duration of dark period.

In Experiments 1-4, illumination began at sunset so that no dark period intervened between the end of natural illumination and the beginning of the artificial. In Experiment 5, however, a dark period of about 5¼ hours was interposed, artificial illumination being supplied from 10 p.m. to 3 a.m. instead of from 5 p.m. to 10 p.m. as in the parallel experiment (Experiment 4) carried out at the same time. The result of this change in timing of the artificial illumination was the appearance, on the fourteenth day of treatment, of leaf abnormalities which rapidly grew worse. There were two types of abnormality : first an evenly diffused, intervenal yellowing which developed into a yellow-green mosaic variegation ; second a down-folding of the edges and tip of leaflets, especially the tip of the distal leaflets. By the end of twenty nights of illumination these plants of Experiment 5 were much smaller than those of

TABLE II.

Experiment	Duration of illumination (hours)	Intensity range (f.c.)	Mean weight per plant (gm.)	
			Control	Illuminated
1	(i) 6	125-425	0·096	0·147-0·361
	(ii) 9	do.	do.	0·177-0·479
2	(i) 6	125-475	0·093	0·220-0·523
	(ii) 10	do.	do.	0·262-0·996
3	10	75-500	0·183	0·470-1·810
4	5	75-725	0·418	0·500-1·440
5	5	do.	do.	0·400-0·850

Experiment 4 which had received precisely the same amount of artificial light. This size difference is shown in the figures for range of plant weight in the two experiments (see Table II).

Thus growth was abnormal and weight much reduced when a dark period of some 5 hours was interposed between the end of the day and the switching on of the lamps. Withrow and Withrow (1949) have shown that unless tomato has at least 6 hours of unbroken darkness, chlorosis will occur. Our results from illuminating during the 10 p.m.-3 a.m. period agree with the Withrows' observations. We found also, in testing whether the light treatment could be applied satisfactorily during the off-peak electricity supply period (7 p.m. to 7 a.m.), that chlorosis will occur if illumination is started at 7 p.m. Chlorosis does not, however, occur with cucumber.

Spectral composition.

Despite the great improvement obtained in seedling growth with groups of fluorescent lamps, it soon became obvious that there were inherent disadvantages in using this type of apparatus. If left in position during the daytime the reflector cast a heavy shadow on the plants which offset the effect of artificial illumination. Thus, it was essential to remove the whole apparatus during the day, and this meant wasting space wherever it was put.

Attention was therefore turned to the possibility of using small but powerful sources of light, fixed in compact reflectors to minimize obstruction of natural light. Tungsten lamps were ruled out because, if used at night, the heat they radiate might induce drawn, soft growth. The remaining sources available were High Pressure Mercury Vapour (H.P.M.V.), Dual (Mercury-tungsten) and Sodium Vapour lamps. Of these, only the Dual gives light approaching the whiteness of the Daylight Fluorescent lamp hitherto used in the experiments. Hence, the first question arising was whether the quality of supplementary artificial light was at all critical for seedling growth.

A preliminary experiment using the above-named lamps suspended at a height of about 3 ft. above the bench, showed that in every case illumination increased the weight of tomatoes Potentate and Ailsa Craig, lettuces Cheshunt Early Giant and 5B and cucumber Butcher's Disease Resister, by a factor of 2 to 3. The Dual lamp tended to induce elongated, " drawn " growth and was omitted in further experiments.

Experiments were now set up to compare the effects of different light sources more critically and to test whether, by means of an appropriate correction factor for each type of lamp, the different photometric readings could be converted into a common scale measuring to a first approximation the radiation intensity effective for growth, since it seemed probable that the effect of visible radiation on rate of carbon assimilation would play the major role in determining the observed effects on rate of seedling growth. It was decided to try correction factors based on the relation between wavelength and assimilation rate at equal incident energy. The assimilation curve used was established for wheat leaves by Hoover (1937). It is shown in Fig. 5 together with the response curve for the selenium cell and the energy distribution curves for two of the lamps used. The curves are drawn so that the maximum of each has a value of 10 arbitrary units. Calculation of correction factors was made over the range 4,000-7,000 Å at intervals of 250 Å for continuous emission curves and at appropriate wavelengths for line emissions using the formula

$$\frac{\sum_{4{,}000\text{Å}}^{7{,}000\text{Å}} (E\lambda C\lambda)}{\sum_{4{,}000\text{Å}}^{7{,}000\text{Å}} (E\lambda P\lambda)}$$

where $E\lambda$, $C\lambda$ and $P\lambda$ are, respectively, lamp energy output, energy utilized in carbon assimilation, and response of the selenium cell at wavelength λ. In this expression the numerator Σ ($E\lambda C\lambda$) integrates in arbitrary units the energy emitted by the lamp in the range 4,000-7,000Å that is effective for carbon assimilation. The denominator Σ ($E\lambda P\lambda$) similarly integrates the energy that is effective for the photo-electric cell response, while the quotient (correction factor) reflects the divergence between the two quantities for a particular light source. For the lamps used in the present experiments the correction factors calculated are : Neon 1·581, Red-blue Fluorescent 1·126, Daylight Fluorescent 0·900, Dual 0·860, Sodium 0·756, Mercury 0·730. Selenium cell readings (foot-candles) multiplied by the appropriate correction factor will be referred to as corrected intensities, or, more precisely, energy assimilation units.

The first evidence on the effect of spectral composition was from a comparison of Daylight and Red-blue Fluorescent lamps lent by courtesy of Messrs. Philips

Electrical, Ltd. The Red-blue lamps were used concurrently with the Daylight ones in Experiment 3 (Table I). The energy distribution curves for these lamps are shown in Fig. 5. The Red-blue lamps were designed to see whether better plant response could be secured by using radiation with a spectral distribution approximating to the wave bands of maximum absorption for carbon assimilation.

The two kinds of lamps, suspended at the same height, 21 in., gave the same readings for light intensity and induced the same seedling response after 3 weeks illumination. Calculation of the variance of the linear regression coefficients shows no significant difference between the weights of the plants irradiated by the two lamps at corresponding intensities (foot-candles), whether the intensity values are

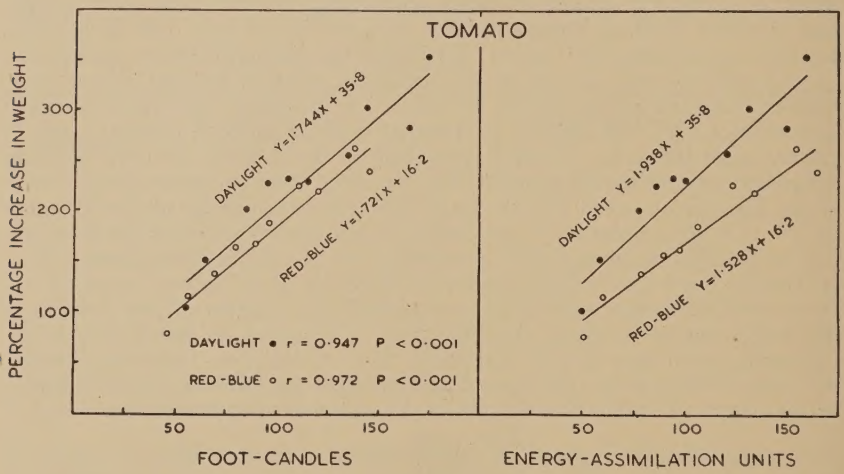

FIG. 3.

Left side, showing correlation of relative increase in plant weight with light intensity, also influence of spectral composition. Right side, showing effect of correction. (Experiment 3.)

corrected or not (Fig. 3 and Table V). Thus, although the quality of the light emitted by the Red-blue lamps (crimson) was entirely different from that emitted by the Daylight lamp (white), the quantity of energy used by the plants and absorbed by the selenium cell must have been the same for both types of lamps.

The next experiment, number 6, was carried out with Neon, Mercury, Sodium and Fluorescent lamps (three 5 ft., 80 watt lamps, spaced 6 in. apart, each with its own reflector). All lamps were installed at a height of $2\frac{1}{2}$ ft. Illumination was for 8 hours a night (3.30 p.m.-11.30 p.m.) for 20 nights at a house temperature of 60° F. Each lamp illuminated 70 plants of tomato Potentate and 70 of lettuce 5B. In order to calculate the correlation between light intensity and growth, for each lamp, measurements of light intensity and of plant weight were made for each individual plant position.

The results were decisive in several respects. First, Fig. 4 shows that increase in plant weight is very significantly correlated with increase in foot-candles for

both the Neon and the Mercury lamps. A similar relation could not be established for the Sodium and Fluorescent lamps owing to the shorter ranges of intensity provided by these lamps.

Table III.

Experiment 6.

Light treatment 20 Nov.-11 Dec., 1952	Mean intensity (foot-candles)		Tomato Potentate	Lettuce 5B
	Tomato	Lettuce		
Average weight/plant (gm.) :				
Control	—	—	0·235	0·249
Relative weight :				
Control	—	—	1·00	1·00
Neon 400 w.	173	174	3·12	3·21
Mercury 400 w.	294	297	2·82	2·59
Average weight/plant (gm.) :				
Control	—	—	0·180	0·231
Relative weight :				
Control	—	—	1·00	1·00
Sodium 140 w.	147	151	1·87	1·61
Fluorescent 3×80 w.	142	156	1·75	1·55

Table IV.

Experiment 6.

Lamp	Relative increase in plant weight		
	per unit area	per unit intensity	
		uncorrected	corrected
Tomato :			
Neon 400 w.	100	100	100
Mercury 400 w.	86	51	109
Sodium 140 w.	41	48	101
Fluorescent 3×80 w.	35	43	76
Lettuce :			
Neon 400 w.	100	100	100
Mercury 400 w.	72	42	91
Sodium 140 w.	28	32	67
Fluorescent 3×80 w.	25	28	49

Secondly, in both tomato and lettuce the regression coefficient on uncorrected light intensities is much greater for the Neon than for the Mercury lamp. This difference is in both cases statistically significant ($P < \cdot001$). Correction to energy assimilation units brings the Neon and Mercury regression slopes close together and there is now no significant difference between the regressions for the two lamps.

We may, alternatively, compare the lamps on the basis of the mean yield and mean light intensity for the 70 plant positions under each lamp. The data are shown in Table III and the comparison is made in Table IV.

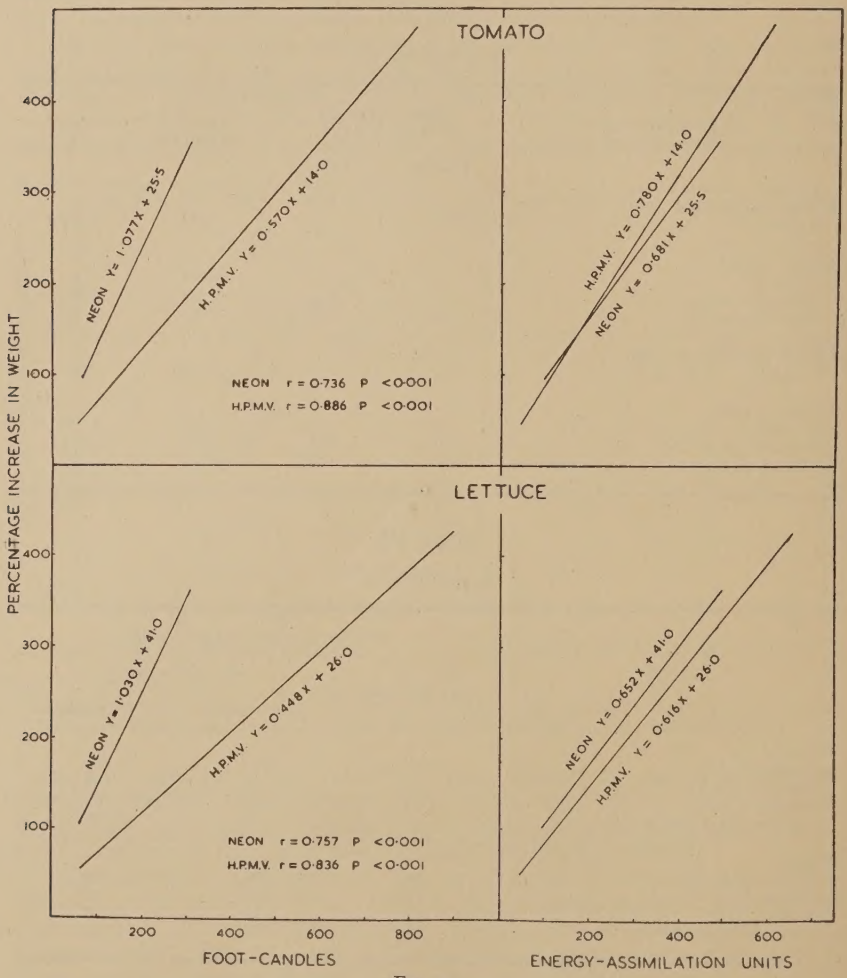
TOMATO
LETTUCE
PERCENTAGE INCREASE IN WEIGHT
FOOT-CANDLES
ENERGY-ASSIMILATION UNITS
NEON Y= 1·077X + 25·5
H.P.M.V. Y= 0·570X + 14·0
NEON r = 0·736 P <0·001
H.P.M.V. r = 0·886 P <0·001
H.P.M.V Y= 0·780X + 14·0
NEON Y= 0·681X + 25·5
NEON Y= 1·030X + 41·0
H.P.M.V Y= 0·448X + 26·0
NEON r = 0·757 P <0·001
H.P.M.V. r = 0·836 P <0·001
NEON Y= 0·652X + 41·0
H.P.M.V. Y= 0·616X + 26·0

FIG. 4.

Left side, showing correlation of relative increase in plant weight with light intensity, also influence of spectral composition. Right side, showing effect of correction. (Experiment 6.)

The Neon lamp is superior to the Mercury on the basis of actual yield increase; it is about twice as efficient on the basis of yield increase per unit of uncorrected light

intensity but about equally efficient on the basis of yield increase per unit of corrected light intensity. This confirms the conclusions from the regression equations for these two lamps.

The Sodium and Fluorescent lamps are, on the basis of actual mean yield, much inferior to the Neon and Mercury. This must, in part, be ascribed to their lower wattage, since, for unit uncorrected light intensity, they approach more closely to the Mercury lamp, while correction brings them, with the Mercury, closer to the Neon. It is interesting to note from Table IV that whereas, in tomato, correction brings all the lamps fairly close together, in lettuce the Sodium and Fluorescent lamps appear still very definitely inferior. This suggests that tomato and lettuce may respond differently to change of spectral composition.

In Experiment 6, the short intensity range of the Sodium lamp prevented a

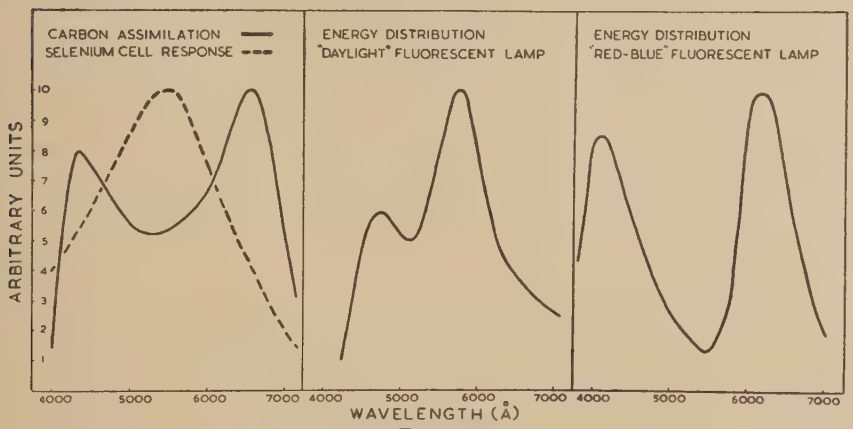

Fig. 5.

Energy distribution curves. Carbon assimilation after Hoover.

satisfactory assessment of its effect on plant behaviour. A final experiment (number 7) was, therefore, made with a Sodium lamp suspended at a height of $2\frac{1}{8}$ feet, giving an intensity range of approximately 50-500 foot-candles. A Mercury lamp was used for comparison at a height of 3 feet to give a similar range. Illumination was for 12 hours a night for 20 days. There were 53 plants per species with the Mercury lamp and 63 with the Sodium. Individual measurements of light and plant weight relative to the controls were made as before. The results were as follows. Both lamps show high correlation coefficients for increase in plant weight with light intensity; in tomato, Mercury $r=+0\cdot765$, Sodium $r=+0\cdot768$, and in lettuce, Mercury $r=+0\cdot764$, Sodium $r=+0\cdot776$. In tomato, the regression coefficient on uncorrected light intensities (see Table V) is greater for the Mercury than for the Sodium lamp ($P=0\cdot04$) and correction to energy assimilation does not alter this relationship, the difference between the regression slopes still being significant ($P=0\cdot02$). In lettuce, the regression coefficients on uncorrected light intensities for the Mercury and Sodium lamps are closely alike (difference not significant) and again correction does not alter this relationship.

Comparison of the uncorrected coefficients for tomato and lettuce in Experiment 7, supports the suggestions from Experiment 6 (Table IV) that tomato responds somewhat differently from lettuce to change of spectral composition.

We have now seen that (1) the only highly significant difference established between growth responses per foot-candle was, as expected on the basis of the Hoover curve, between Neon and Mercury lamps, and (2) correction from foot-candles to energy assimilation units brings Neon and Mercury lamps into line. One further comparison can be made, namely, the response of the selenium cell to the same total amount of visible radiant energy provided by the different types of lamps. To make this calculation, $C\lambda$ is put equal to unity in the formula given on page 161. The resultant *lamp factors* are found to be: Neon 1·00, Daylight Fluorescent 0·73, Red-blue Fluorescent 0·917, Dual 0·80, Mercury 0·71 and Sodium 0·66. We can now compare all the uncorrected regression coefficients from Experiments 3, 6 and 7 with those corrected to (*a*) energy assimilation units and (*b*) lamp energy units (see Table V).

TABLE V.

Treatment	Regression coefficients y= Uncorrected: Foot-candles	Corrected: Energy assimilation units	Corrected: Lamp energy units
TOMATO:			
Experiment 3			
Daylight Fluorescent	1·744x+35·8	1·938x*	2·389x*
Red-blue Fluorescent	1·721x+16·2 *not sig.*	1·528x *not sig.*	1·877x *not sig.*
TOMATO:			
Experiment 6			
Neon	1·077x+25·5	0·681x	1·077x
Mercury	0·570x+14·0 P<0·001	0·781x *not sig.*	0·803x P=0·04
Experiment 7			
Mercury	1·042x+83·0	1·427x	1·468x
Sodium	0·721x+33·7 P=0·04	0·954x P=0·02	1·092x *not sig.*
LETTUCE:			
Experiment 6			
Neon	1·030x+41·0	0·651x	1·030x
Mercury	0·448x+26·0 P<0·001	0·614x *not sig.*	0·631x P=0·001
Experiment 7			
Mercury	0·747x+30·0	1·023x	1·052x
Sodium	0·726x+61·0 *not sig.*	0·960x *not sig.*	1·100x *not sig.*

* Correction does not alter the value of c in the equation $y=mx+c$.

It is at once clear that correction based on lamp energy does not give so good a fit as correction based on assimilation energy, i.e. equal lamp energy does not induce equal growth response.

We may summarize our findings on the effect of the spectral composition of supplementary artificial illumination of similar intensity as follows :

1. Comparison of Daylight and Red-blue Fluorescent lamps showed no difference in growth response per unit foot-candle with tomato.

2. Comparison of Neon and Mercury lamps showed distinct differences in growth response per unit foot-candle with both tomato and lettuce.

3. Comparison of Mercury and Sodium lamps showed no difference in growth response per unit foot-candle with tomato or lettuce.

4. The only substantial or significant difference established between the growth responses per foot-candle was that between Neon and Mercury lamps which on the basis of the Hoover assimilation curve, would be expected to show such differences. Moreover, in lettuce, correction from foot-candles to energy assimilation units brought the Neon and Mercury lamps into line without disturbing the equivalence of the Mercury and Sodium lamps which have practically the same correction factor. In tomato, this is not shown quite so clearly but it seems a similar conclusion may be warranted. Correction brought the Red-blue Fluorescent rather below the Daylight Fluorescent in efficiency but the difference was not statistically significant.

5. Correction from foot-candles to equal lamp energy units did not bring the Neon and Mercury lamps into line.

6. For the purposes of practical illumination, Neon and Mercury lamps are superior to Sodium and Fluorescent, since high enough intensities cannot be conveniently obtained with the latter.

Temperature.

The question may be asked, is not the improved growth of illuminated plants due in part to the higher air temperature beneath discharge lamps such as Neon and Mercury ?

An answer was obtained by enclosing four 100-watt tungsten lamps in a black, light-proof metal box and suspending it over a batch of 140 plants at the same height as a 400-watt Mercury lamp. Unheated, unlighted batches of plants were grown on either side as controls. The house temperature was 60° F. In October-November, heated plants of tomato and cucumber were respectively 21 per cent. and 10 per cent. heavier than the controls (lighted plants 92 per cent. and 63 per cent. heavier). In November-December, heated plants of tomato and lettuce were 4 per cent. and 2 per cent. lighter in weight than the controls (lighted plants 182 per cent. and 159 per cent. heavier). These results indicate that although the heat from, say, 400-watt Mercury and Neon lamps may be responsible for a small increase in plant weight, by far the larger increase is induced by the artificial light, especially in mid-winter when natural light is poor.

It should also be pointed out that in most of the experiments reported here a glasshouse temperature of 60° F. was closely maintained day and night, not because this was thought to be ideal but as a compromise which would enable such different species as tomatoes and lettuces to be grown together moderately well.

Seedling illumination and crop yields.

Three experiments were made in which tomato seedlings were illuminated and then grown on and planted out under glass in the usual way for a main crop. Assemblies of Daylight Fluorescent lamps, which were removed from over the plants during

the daytime, were used for the first two experiments. In the third experiment, fixed Mercury lamps were employed.

The details of the first of these experiments, Experiment 8, are given in Table VI. Two composts were used, JIS and JIP1, and two methods of raising the plants, (1) pricking out direct into pots, (2) spaced sowing, 54 seeds/box followed by potting off. Illumination was for 6 hours/night for the first 20 nights after pricking out.

TABLE VI.

Experiment 8.

Tomato :	Potentate	Picking began :	10 June
Sown :	3 Jan., 1947	Picking ended :	28 Aug.
Planted out :	22 Mar. to 4 April	Trusses per plant :	7
Illuminated : (*a*)	Fluorescent lamps, 500 f.c.	Plants per treatment :	20
(*b*)	4 p.m.-10 p.m.	Blocks :	4
(*c*)	13 Jan.-2 Feb.		

Treatment			Average per plant (oz.)	
Artificial light	Method of raising	Compost	of ripe fruit in first 3 weeks	of total crop
Illuminated	Pots	JIP1	28·3	110·1
,,	,,	JIS	20·8	107·9
,,	Boxes-Pots	JIP1	19·5	100·8
,,	,, ,,	JIS	19·0	109·5
Not illuminated	Pots	JIP1	18·2	107·3
,, ,,	,,	JIS	14·4	97·0
,, ,,	Boxes-Pots	JIP1	10·8	89·7
,, ,,	,, ,,	JIS	9·5	90·0

	Increase in weight (oz.)	
	first 3 weeks	total crop
Illuminated versus not illuminated	8·7 (P<0·001)	11·1 (P<0·01>0·001)
Pots versus Boxes-Pots	5·7 (P<0·001)	8·1 (P=0·03)
JIP1 versus JIS	3·3 (P=0·03)	0·9 (P>0·9)

For growing on, a selection was made of plants illuminated at 500 f.c. The plants varied in rate of development as between the different propagation treatments; therefore planting was carried out as the plants in a given treatment reached the conventional size.

The fruit was picked and weighed weekly. The results are summarized in Table VI. They show that the yield of ripe fruit in the first three weeks of picking can be substantially and significantly increased by (1) using JIP1 instead of JIS, (2) eliminating potting off from boxes and (3) illuminating seedlings while they are quite young.

Examination of the records for weekly pickings shows that the illuminated plants out-yielded the controls for the first 4 to 7 weeks, depending on the other treatments involved, i.e. JIP1 or JIS, potting or boxing. Thereafter, the weekly pickings from the illuminated plants were either the same as or smaller than those from the controls, depending on the other treatments. But any decreases in the weekly yields of the illuminated plants in the later weeks of cropping were insufficient to offset the increase built up in the early weeks. In consequence, the total crop from the illuminated plants was never smaller and was usually larger than that from the control plants. These results are similar to those obtained by Withrow (1946), who used a tungsten lamp with internal reflectors for illuminating American varieties of tomato grown at temperatures between 70° F. and 75° F.

The situation revealed by comparing illuminated and control plants for each of the four treatments in Experiment 8 (Table VII) is of some interest. In both the early and total yields, illumination has its greatest relative effect when the method of propagation is poorest, each successive improvement in method resulting in a smaller relative increase in yield from illumination.

Table VII.

Experiment 8.

Treatment (see Table VI)	Yield per plant (oz.)					
	First three weeks			Total crop		
	Illuminated	Control	Per cent. increase	Illuminated	Control	Per cent. increase
Pots	24·6	17·5	41	107	101	6
JIP1	23·9	15·7	52	106	94	13
JIS	19·9	11·9	67	107	93	15
Boxes	19·3	10·2	89	105	80	31

In the second experiment on crop yield, Experiment 9, some of the plants were raised with the aid of Daylight and some with Red-blue Fluorescent lamps. A selection was then made of plants illuminated by Daylight tubes at 500 and 250 f.c., and by Red-blue at 250 f.c. and these plants were grown on and planted out under glass and the yields recorded week by week. The detailed results of Experiment 9 are given in Table VIII and may be summarized as follows :

1. The yield of early fruit (first three weeks of picking) was increased by 12·6 oz. per plant when the seedlings were illuminated at 500 f.c. and by 10·7 oz. per plant from illumination at 250 f.c.

2. Total yield was similarly increased by 16·0 oz. and 10·3 oz. per plant respectively.

3. The Red-blue tubes gave results practically identical with the Daylight ones.

TABLE VIII.

Experiment 9.

Tomato :	Potentate	Planted out :	14 Feb.-5 Mar.
Sown :	1 Jan., 1948	Picking began :	26 May
Pricked out :	8 Jan.	Picking ended :	5 Aug.
Illuminated : (*a*)	4 p.m.-2 a.m.	Trusses :	7
(*b*)	8-20 Jan.	Plants per treatment :	20
		Blocks :	4

Yield of ripe fruit to end of :	Cumulative yield, oz. per plant				Increase from illumination with Daylight 500 f.c.
	Control	Red-blue 250 f.c.	Daylight		
			250 f.c.	500 f.c.	
1st week ..	2·1	4·3	4·2	4·8	2·7
2nd ,, ..	7·6	13·9	13·5	14·5	6·9
3rd ,, ..	16·9	26·2	27·6	29·5	12·6*
4th ,, ..	30·0	41·6	42·2	45·8	15·8
5th ,, ..	39·1	51·4	51·1	55·9	16·8
6th ,, ..	51·6	65·2	66·0	72·0	20·4
7th ,, ..	60·5	74·9	75·2	82·2	21·7
8th ,, ..	71·1	84·9	84·7	92·2	21·1
9th ,, ..	79·3	91·6	91·5	98·6	19·3
10th ,, ..	86·6	96·0	99·0	102·0	15·4
11th ,, ..	92·7	100·4	103·0	107·7	15·0
Total green and ripe fruit ..	100·4	109·0	110·7	116·4	16·0†

* Significantly greater than control, $P=0{\cdot}001$.

† Not significantly greater than control, $P<0{\cdot}1>0{\cdot}05$.

TABLE IX.

Experiment 10.

Tomato :	Potentate	Planted out :	1 Jan. (illuminated)
Sown :	6 Dec., 1951		16 Jan. (controls)
Pricked out :	14 Dec.	Picking began :	23 May
Illuminated : (*a*)	H.P.M.V. lamps, average 220 f.c.	Picking ended :	14 Aug.
		Trusses :	10
(*b*)	8 a.m.-2 a.m.	Plants per treatment :	40
(*c*)	15 Dec.-3 Jan.	Blocks :	8

Yield of ripe fruit to end of :	Cumulative yield, oz. per plant		Increase from illumination
	Control	H.P.M.V.	
1st week	0·2	1·6	1·4
2nd ,, ...	3·6	10·7	7·1
3rd ,, ...	8·6	20·0	11·4*
4th ,, ...	18·7	35·6	16·9
5th ,, ...	33·3	53·5	20·2
6th ,, ...	50·5	72·0	21·5
7th ,, ...	70·0	93·8	23·8
8th ,, ...	91·5	113·7	22·2
9th ,, ...	100·3	120·2	19·9
10th ,, ...	105·7	126·1	20·4
11th ,, ...	110·4	131·5	21·1
12th ,, ...	118·9	141·4	22·5
13th ,, ...	130·1	153·1	23·0
Total green and ripe fruit	160·4	178·5	18·1*

* Significantly greater than control, $P<0{\cdot}001$.

Experiment 10 was made at Hertford using H.P.M.V. lamps and it thus differed from Experiments 8 and 9, made at Merton, using Fluorescent lamps. Details are given in Table IX.

A special study was made of the effect of illumination on time of flowering. Illuminated plants, on average, flowered 8·5 days earlier than did the controls (see Fig. 6). It is noteworthy that the effect of illumination persisted to the tenth and

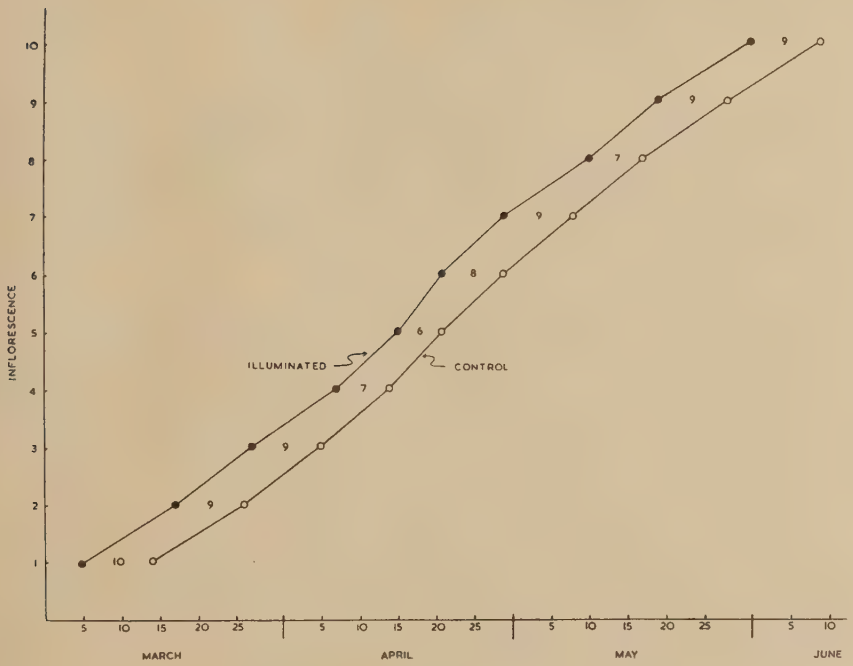

Fig. 6.

Average time of flowering of 10 successive inflorescences in tomato Potentate (160 plants per treatment). Numerals between the curves show precocity (days) of illuminated over control plants at each inflorescence. (Experiment 10.)

final inflorescence. If allowance is made for the effects of variation in weather from week to week on plants at different stages of development, then we may conclude that illuminated plants will, in general, flower ahead of non-illuminated plants, equally for all inflorescences, i.e. development is precocious throughout the life of the plant.

Yields are given in Table IX. Illumination resulted in an increase of 11·4 oz. fruit per plant in the first 3 weeks of picking and 18·1 oz. per plant for the whole crop.

Thus, highly satisfactory results from supplementary illumination have been obtained under the very different natural light conditions obtaining in the Merton and Hertford glasshouses, and with both Fluorescent and Mercury lamps. Photographs of typical plants to illustrate the response to artificial illumination are given in Figs. 7a-7c.

Record was also kept of the effects of artificial illumination on the flowering of 24 cucumber plants. Again, both Fluorescent and Mercury lamps induced flowering 14 days ahead of the controls.

DISCUSSION.

The literature on the use of artificial light to sustain and promote plant growth is voluminous and complex, especially that bearing on the relation of wavelength to photosynthetic activity (Duggar, 1936; Crocker, 1948; Borthwick, 1948; Went, 1945). Our object has been simpler, namely, to find an economical way of employing artificial light as a useful supplement to winter daylight, noting at the same time any effects relating to the composition (wavelength), intensity and duration of illumination.

Considering firstly the quantity of light, it has been frequently emphasized (e.g. Lawrence, 1950) that, during the winter months in Britain, light is the limiting factor for the growth of plants under glass. This statement, originally based on empirical observations, is fully substantiated by the results of the experiments described in this paper. That the photoperiod was not a limiting factor in our investigations is clear from Experiments 1 and 2. In these, comparison of $14\frac{3}{4}$ with $17\frac{3}{4}$ total hours illumination (natural plus artificial) and 14 with 18, showed high correlation between foot-candle-hours artificial light and plant weight, irrespective of photoperiod, i.e. quantity of light is the chief limiting factor.

Secondly, regarding composition of light, before the advent of the modern discharge lamps with high lumens output, research workers were unable to obtain satisfactory results from the use of lamps of the Mercury and Sodium vapour type and it was assumed that the composition of the light was unsuitable for promoting seedling growth (e.g. Roodenburg, 1940).

The work of Roodenburg (1950), van de Veen (1949) and Reinders (1950), together with our own, now shows that if the supplementary light is sufficiently intense, the spectral composition is not of first importance for photosynthesis, i.e. other factors such as the size, wattage, life of the lamp, may be of equal, or greater, importance.

Nevertheless, our experiments have demonstrated that increase in plant weight per foot-candle may vary according to spectral composition (cf. Neon and Mercury lamps). The degree of such variation is mainly dependent upon wavelength but the heat from the lamp, the species of plant (cf. tomato and lettuce) and the season, are also concerned.

The most important aspect of the effect of spectral composition is in the comparison of the regressions of plant weight on light intensity. In lettuce, no significant differences were found when light intensity values were corrected on the basis of Hoover's assimilation curve. In tomato this was also true in the comparison of the Neon and Mercury lamps. The position was not quite so clear in tomato when

Mercury and Sodium lamps were compared, since the growth responses per foot-candle differed somewhat as between Mercury and Sodium lamps. However, this difference was only just significant ($P=0\cdot04$) and, as in the corresponding example in lettuce, correction to energy assimilation units did not disturb the relationship. The fact that lamps having similar Hoover correction factors induce similar increases in the weight of tomato and lettuce plants per unit foot-candle, despite large differences in the spectral composition of the light, shows that the carbon assimilation curve calculated by Hoover for wheat is approximately correct for tomato and lettuce. This might not be true for older plants or leathery-leaved species. In young seedlings of soft-leaved species, such as tomato and lettuce, the leaves are thin and there is a minimum of overlapping. Therefore, differences in spectral response between species will also be at a minimum.

It should be noted that a Red-blue lamp designed to have an energy emission curve approximating to that for carbon assimilation proved no better than a lamp emitting white light. Other things being equal, it seems that a more efficient lamp for carbon assimilation would be one emitting all its energy in the 6,000-7,000Å waveband, e.g. Neon.

SUMMARY.

1. An account is given of the results of supplementary illumination of tomato, lettuce and cucumber seedlings, under normal glasshouse conditions, in winter time.

2. In five types of discharge lamp, increase in plant weight is very significantly correlated with increase in foot-candles artificial illumination.

3. Comparison between lamps showed that plant response per unit illuminated area was in the order Neon, Mercury, Sodium, Fluorescent, the first two lamps being superior to the last two. The fifth lamp, Mercury-tungsten, induced "drawn" growth and was not satisfactory.

4. The regressions of light intensity (foot-candles) on increase in plant weight of tomato and lettuce seedlings irradiated by Neon, Mercury and Sodium lamps, showed a substantial difference between Neon and Mercury lamps but not between Mercury and Sodium. No substantial differences were found when the intensity values were corrected by factors based on Hoover's carbon assimilation curve for wheat. Correction based on lamp energy factors was not satisfactory.

5. Though plant response may vary according to the spectral composition of the light, the chief consideration for practical illumination is light intensity. To be adequate, the mean intensity must be of the order of 300-500 foot-candles as measured by a selenium photocell.

6. After taking economic and installation factors into consideration, the 400 w. High Pressure Mercury Vapour lamp was selected as the most suitable light source for the illumination of seedlings.

7. In some of the experiments, tomatoes which had been illuminated as seedlings were grown on in the glasshouse beds as main crops. The increase in the yield of ripe fruit in the first 3 weeks of cropping was 8 to 12 oz. per plant and the increase in total crop 16 to 21 oz. or more a plant.

8. Unless tomato plants have an unbroken period of about 6 hours of darkness each day, chlorosis and distortion of the leaves occur and growth is correspondingly retarded. This does not apply to cucumber.

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PLATE I

Fig. 2.

Tomato. Showing relation between plant size and intensity of supplementary artificial illumination (0-500 foot-candles). Seedlings illuminated 10 hours a night for 20 nights and photographed when 3 weeks old.

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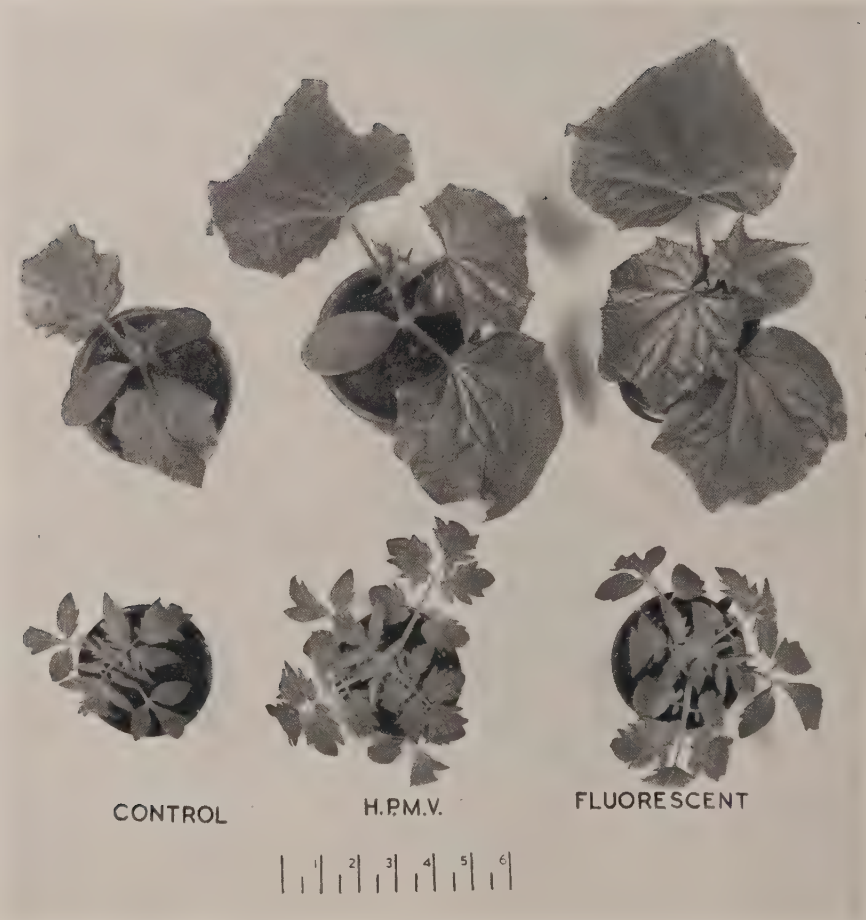

FIG. 7A.
Showing effect of supplementary illumination on plants' growth and yield. Plants 3 weeks old.

FIG. 7B.

Showing effect of supplementary illumination on plants' growth and yield. Plants 3 months old.

FIG. 7c.

Showing effect of supplementary illumination on plants' growth and yield. Plants 5 months old.

THE REINVIGORATION OF APPLE TREES BY INARCHING

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The invigoration of weak and stunted apple trees by inarching them with vigorous rootstocks was described by Hearman, Beakbane, Hatton and Roach (1937) after three seasons' growth following the inarching. The present paper records data obtained later from this experiment.

Material.

The material consisted of three trees each of Grenadier on Northern Spy and Malling Crab H rootstocks, the trunks of which were inarched in 1934 with two or three M.XVI rootstocks ; one tree of Grenadier on Malling Crab H with an inarch of M.XVI inserted into one branch above the crotch ; and ten control trees (six Grenadier on Northern Spy and four on Malling Crab H).

Observations on standing trees.

At the end of the third season the growth of most of the trees was markedly lopsided ; the cause of this was traced to the localized effect of the inarches along the conducting tissues in direct vascular connection with the inarches. Raised ridges could be traced, partly visually and partly by feeling with the fingers, from the inarches up the trunk ; in one tree these observations were supplemented by injections made, one at each side of the group of inarches, so as to mark the junction between the tissues in direct connection with the original rootstock (Hearman *et al.*, *loc. cit.*, p. 386). These raised ridges of stem were marked with white paint. These marks were still visible when the final examinations of the trees were made ten and fifteen years later, but no ridges could be detected.

The tops became even more markedly lopsided for a time, as may be seen by comparing Fig. 1 with Fig. 3 in the first paper ; later the effect became less obvious, apparently because the invigorating effect had spread over a larger and larger fraction of the tree. But this statement does not apply to the tree in which a single inarch was inserted into a branch a little above the crotch, as may be seen by comparing Figs. 2 and 5 with Fig. 4 in the first paper. Whereas in 1937 the inarched branch made up about one quarter of the top, in 1949 it made up about three quarters of the top and the inarch stem had become slightly larger than the original main stem of the tree (see Fig. 5).

Survey of conducting tissues by dye injections.

The trunk and inarches of the inarched trees were sawn through at ground level and the tops were suspended so that the cut end of each trunk and each inarch dipped into a vessel containing a dye solution of a distinctive colour. They were left for a day or so until the leaves were visibly coloured, when the bark was removed to expose

the dyed stems, which were treated with sulphurous acid to prevent them from turning brown. Thus in three trees it could be seen at a glance which parts of the trees had been nourished by the original stem and which by the inarches. A sketch of one of these trees is shown in Fig. 3. In the remaining trees the stems of the inarches and the trunk had grown so close together that there was some mixing of the dyes before absorption. This was due to the fact that, as a result of liquid level falling more rapidly in one container than in another, the liquid crept by capillarity over the wet surfaces from the higher to the lower level. Attempts to prevent this with a vaseline barrier failed.

In each of the three trees the tissues in direct connection with the inarches had moved to the right compared with the white lines made in 1937. This fact would explain why the raised ridge could no longer be traced up the stem because it would grow each year slightly to the right of the position occupied the year before and the two edges in a period of years would move round the stem, resulting in a smooth, rather than a sudden, increase in total stem " diameter ". It would also lead to a gradual spreading of the influence of the inarches to an increasing fraction of the tree.

Further information was obtained by cutting and polishing sections through the main trunk and branches. A photograph of such a section, cut through the branch into which an inarch was inserted, is shown in Fig. 4. The section was cut at X, Fig. 5, just above the tip of the inarch. This will be described in detail because it epitomizes the information gathered from the rest of the trees. The inarch was inserted below *H*, Fig. 4. By following the annual ring round to the opposite side, i.e. to *C*, it will be seen that the inarch was inserted into the weaker side of the branch because the " radius " *HF* is less than the radius *FC*. The ratio *HF*/*FC* is 0·6. After the inarching, however, much more growth was made on the side over the inarch. The ratio *KH*/*CD* is 7·6. The division between the tissues in direct connection with the inarch and those in direct connection with the original rootstock, as indicated by the injected dyes, runs approximately along the dotted line.

The most marked decrease in thickness of annual ring, passing from the inarch side to the other side, also takes place mainly along this line. The amount of this change varies from ring to ring. It is well marked in the penultimate one. There is a smooth but fairly rapid decrease in thickness in passing from the inarch to the original rootstock side at *A*. This is followed by a less rapid, but still definite, decrease between *A* and *B* ; and from *B* to *E*, on the side opposite the inarch, there is also a perceptible decrease in thickness. Thus even in this latter region, there is a reversal of the gradient in annual ring thickness after inarching. The same tendencies may be seen on the other side of the branch, but the decrease in thickness of the rings in passing from the inarch side to the opposite side tend to be smoother. This gradual taper of the rings in the part of the branch remote from the inarch, which is the reverse of that existing before the inarching was done, suggests that at least the quantitative effect of the inarching may not be confined entirely to the tissues in direct connection with the inarch. The fraction of the first annual ring in direct connection with the inarch was about one-fifth of the whole, whereas in the last year it was more than a half.

The growth of the conducting strands always to the right of the ones laid down previously is indicated clearly on the right hand side of Fig. 4 by the fact that the dotted line crosses a " radial " crack. Cracks tend to be radial but they are distorted in this instance because of the unequal growth on the two sides of the branch.

FIG. 3.
Tree 1 after injection, showing position of dyes in the trunk, inarches, and branches.

=Acid Fuchsin
=Light Green
=Water
=Orange G.

POMOLOGICAL INVESTIGATIONS.

Cross-sectional area of stem.

The cross-sectional area of the trunk before and after inarching is shown for each tree in Table I. The increments made after inarching up to 1943 and up to 1949 are expressed as percentages of the stem cross-sectional area before inarching and are shown in the last two columns.

TABLE I.

Stem cross-sectional area (sq. cm.) before and after inarching, and increments up to 1943 and 1949 expressed as percentages of the area at inarching.

Rootstock	Tree No.	Cross-sectional area			% increment	
		1934 before inarching	1943	1949	1934 to 1943	1934 to 1949
Northern Spy inarched	1	24·9	54·6	—	119	—
	2	57·6	112·5	162·6	95	182
	4	58·9	127·3	190·3	116	223
Northern Spy controls	10	43·2	78·0	94·7	81	119
	12	45·8	80·0	94·7	75	107
	14	38·5	73·1	94·7	90	146
	8	49·7	92·0	120·4	85	142
	16	56·3	102·0	122·3	81	117
	18	68·8	136·4	174·3	98	153
Malling Crab H inarched	5	12·0	47·4	113·1	295	842
	6	21·9	62·4	129·9	185	493
	7	24·6	66·5	—	170	—
Malling Crab H controls	19	24·9	40·6	55·5	63	123
	17	27·2	48·9	66·0	80	143
	13	27·5	46·6	60·6	69	120
	113	69·3	130·5	181·1	88	161
Malling Crab H, one branch inarched	3	14·1	36·8	69·2	161	391

It will be seen that two out of the three percentage increment figures for 1934 to 1943 for the inarched trees on Northern Spy are larger than those for any of the untreated trees and that the remaining one, viz. 95 per cent., is only slightly less than the largest of the latter figures, viz. 98 per cent. ; but by 1949 these two figures also come in the same order as the others. The figures for all three inarched trees on Malling Crab H are much larger than any of those for the four untreated trees. The chances of getting these two orders of figures by accident are 1 in 84 and 1 in 35 respectively. With Tree 3, on Malling Crab H, where one branch had been inarched, the stem cross-sectional area was nearly three times as large by 1943, and by 1949 had increased to nearly five times its original area.

Cross-sectional areas of branches and shoot extension growth.

Cross-sectional areas and shoot extension growth were recorded annually for each main branch on the inarched trees. The data are used in Table II to compare the

growth made after inarching with that made before inarching. The figures in the last double column were obtained by dividing the sum of the annual shoot extension growths for the periods 1936-44 and 1936-49 by the corresponding totals for the period up to, and including, 1935. The figures in the other double column were

TABLE II.

Cross-sectional areas and shoot extension growth of the main branches of inarched trees.

Tree No.	Rootstock	Order of branches		Cross-sectional area		Shoot growth	
		Predicted	Actual	1944–1936 / 1936	1949–1936 / 1936	1936–1944 up to 1935	1936–1949 up to 1935
3	Malling Crab H	4	4	2·7	8·3	7·7	26·0
		1, 2, 3	1, 2, 3	0·5	0·8	0·8	2·2
7	Malling Crab H	4	4	3·5	—	16·0	—
		1	1	1·3	—	6·0	—
		2, 3	2	0·3	—	1·6	—
			3	0·0	—	1·4	—
5	Malling Crab H	4	4	4·1	10·6	17·0	51·0
		1	1	2·4	6·3	8·2	25·0
		2, 3, 5	5	2·5	2·4	6·5	8·4
			3	0·9	1·4	2·9	4·8
			2	0·8	1·0	2·3	5·2
6	Malling Crab H	1	1	3·0	6·3	14·0	43·0
		2	3*	2·4 / 0·5	6·0 / 0·6	8·2	21·0
		3*	2	1·2	1·2	4·0	9·6
4	Northern Spy	4	4	1·0	2·0	3·0	9·1
		2	2	0·6	1·1	3·7	9·5
		1, 3	1	0·4	0·7	1·8	3·9
			3	0·4	0·5	0·5	1·1
1	Northern Spy	1	1	1·7	—	4·4	—
		3, 4	3	1·4	—	2·9	—
			4	0·3	—		
		2	2	0·9	—	2·3	—
2	Northern Spy	1	1	0·7	1·7	1·9	5·1
		2*	2	0·6	1·3	2·3	6·6
		3, 4, 5, 6	3	0·3	0·7	1·2	2·4
			5	0·3	0·5	0·7	1·7
			4	0·2	0·3	0·7	1·0
			6	0·3	0·3	0·6	0·6

* See text, p. 180.

obtained by dividing the increment in cross-sectional area made in the same two periods by the cross-sectional area recorded in 1936. This date was selected because the data were incomplete at the time of inarching. The branches are arranged in descending order of ratios. The order given by the two measurements of vigour, branch cross-sectional area and shoot growth, are practically identical. The branch

numbers are given in column 4 and their order may be compared with that given in column 3, which was the order predicted in 1936 as a result of visual and tactual examination of the ridge of thickening passing up the main stem from the inarches (Hearman *et al.*, *loc. cit.*, pp. 382-6, Figs. 5-16). The asterisks indicate branches which have been influenced as a result of the growth of conducting tissues to the right of those laid down immediately before them, as already mentioned (p. 176). There is close agreement between the predicted and the actual result and agreement is almost perfect when this increasing twist is taken into account. Thus, for Tree 6 in the Table, Branch 3 actually comes second instead of third, as predicted. As can be seen from Figs. 11 and 12 in the first paper, the ridge of thickening in 1936 just touched Branch 3 without apparently passing up it. The distribution of dye proved that with age the increasing right-handed twist of the tissues had resulted in Branch 3 being supplied to an increasing extent by the inarches. With Tree 1, Branch 1 comes first, as predicted. This one actually came last in 1936 (see Table VII, p. 385 in the first paper). Sixteen years after inarching the invigorating effect is still distributed unevenly amongst the main branches, but the relative increase in vigour is much greater for the trees on Malling Crab H than for those on Northern Spy, a fact in harmony with the greater difference in vigour between M.XVI and Malling Crab H than between M.XVI and Northern Spy.

Fruit yield and quality.

The average yields per tree for the two five-year periods before, and the three five-year periods after, inarching are given in Table III. The inarched trees yielded less than the control trees until the last period, when the inarched trees yielded more heavily than the controls. This was so for trees on both Northern Spy and Malling Crab H rootstocks.

TABLE III.

Mean fruit yield (lb. per tree).

		Before inarching		After inarching		
		1925/9	30/4	35/9	40/4	45/49
Northern Spy	Control	21	180	236	265	294
	Inarched	23	155	208	249	477
Malling Crab H	Control	14	136	150	187	234
	Inarched	14	78	77	94	288

Records of fruit size showed that this was not affected appreciably in trees on Northern Spy but, in those on Malling Crab H, the fruit on branches affected by the inarches was slightly larger.

The variety Grenadier, normally a green apple, sometimes assumes a brownish flush, generally under adverse conditions. This occurred in 1942 and a fruit colour record showed that inarched trees had less brown-coloured fruit than the control trees.

Leaf scorch.

In 1942 and 1945 there was an obvious reduction in the severity of leaf scorch as a result of inarching. This is borne out by the records given in Table IV. The effect was most obvious in the trees on Malling Crab H.

TABLE IV.

Leaf observations.

		Scorch	
		1942	1945
Northern Spy	Inarched	2·7	1·7
	Control	3·5	1·8
Malling Crab H	Inarched	1·0	0·1
	Control	3·7	2·0
Malling Crab H	Inarched branch	—	0·0
	Control branches	—	0·7

Key : Scorch. 0=No scorched leaves
1=1-20 per cent. leaves scorched
5=81-100 per cent. leaves scorched

ROOT EXCAVATIONS.

Four trees were excavated by the " Skeleton " method (Rogers and Vyvyan, 1928) ; Trees 1 and 7 were excavated during the winter 1944-45 and Trees 2 and 3 during that of 1949-50. When the trunk and inarches were sawn through and removed, the remaining portions were injected, at ground level, with different coloured dye solutions, thus facilitating identification of the different component root systems during excavation ; this worked well, except that where root grafts had occurred there was mixing of the dye solutions.

The trees were growing on a shallow soil of the Malling series of sandy-loam texture. This is a drift soil overlying Ragstone, with a dark brown, sticky horizon at the juncture (Bane and Gethin Jones, 1934). During the excavations all roots were traced except the very deepest ones that descended into the Ragstone. The trenches were ½ metre wide and extended to 3 or 4 metres in length ; the depth at which rock was encountered varied from 15 to 80 cm.

Trees 1 and 7.

The Northern Spy root system of Tree 1 was extensive and the main roots shallow and fibrous ; this system was predominant over the combined root systems of the inarched M.XVI rootstocks (Fig. 6). Two of the M.XVI systems were of some length but the third and central one was poor and descended vertically into the rock underneath the tree trunk. Vigorous roots from neighbouring trees were found close to and often mixed with those of Northern Spy. Several natural root grafts were observed between the M.XVI root systems and one instance of M.XVI naturally grafted to Northern Spy was recorded.

Tree 7, originally on Malling Crab H, was growing in a greater depth of soil, the rock being generally well below 72 cm. in depth. The most noticeable feature of this excavation was the predominance of the M.XVI root systems which had deve-

loped vigorously and extensively (Fig. 7). They had formed a mass of intermixed roots and many natural root grafts were observed. No such grafts were observed, however, between the Malling Crab H and M.XVI root systems. Neighbouring roots from other trees approached the root systems of this tree, but in contrast to the previous tree, they turned away sharply.

The weights of the complete root systems for both trees were very similar. That for Tree 1 was 34 lb. and for Tree 7, 37 lb. which includes some 2-4 inches of tree trunk.

The most striking difference between these two trees is the greater extent of the original Northern Spy root system of Tree 1 relative to that of its inarched M.XVI root system, which contrasts with the Malling Crab H root system of Tree 7 where the M.XVI root system predominated. This will be referred to again later.

Trees 2 and 3.

The excavation of Tree 2 showed no very striking differences from that of Tree 1, carried out five years previously. Tree 3, however, showed that the root system of the single M.XVI rootstock which was inarched to a primary branch, was more extensive than the original Malling Crab H root system (Fig. 8). The root weights of these trees are shown in Table V.

TABLE V.

*Root excavations : weight of root systems in lb.**

				Total
Tree 2	Northern Spy roots		19·2	
	M.XVI roots (3) (1) 2·6			
	(2) 2·6			
	(3) 3·1		8·3	27·5
Tree 3	Malling Crab H roots		4·2	
	M.XVI roots		6·9	11·1

* Roots severed 1 ft. away from base of trunk.

DISCUSSION.

This work has shown that it is possible to invigorate weak and stunted apple trees by inarching them with vigorous rootstocks. The positioning of the inarches, however, appears to be an important consideration and is complicated by the practical necessity of placing them where no main tree root already exists. An unbalanced tree head may result from the unilateral inarching of invigorating rootstocks as shown by reference to Figs. 1, 2 and 4 and to the branch cross-sectional areas of inarched trees (Table II). It can be seen that although an equivalent effect on the tree can be obtained either by inarching three rootstocks unilaterally into the trunk, or by inarching one rootstock directly into a primary branch, the tree head is, nevertheless, extremely unbalanced.

The much more balanced top obtained by two inarches on opposite sides of the main stem suggests that the points of insertion of the inarches should be spaced evenly around the main stem. They should also be below the junction between two branches rather than immediately below a branch.

PLATE I

Fig. 1.

Tree 7. Grenadier on Malling Crab H, with three M.XVI rootstocks inarched into the trunk, 8 years after inarching.

Fig. 2.

Tree 3. Grenadier on Malling Crab H, with one M.XVI rootstock inarched into a primary branch, 8 years after inarching.

PLATE II

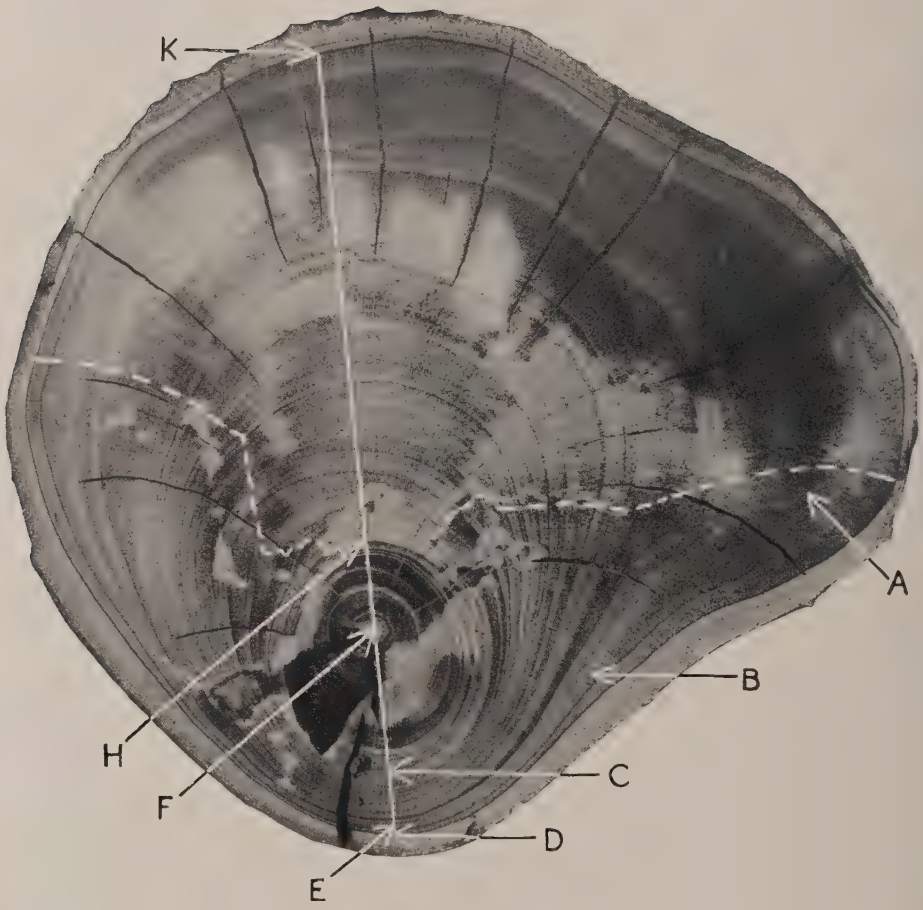

FIG. 4.

Photograph of transverse section of branch 4 of Tree 3 made just above the insertion of the inarch.

FIG. 5.

Tree 3, 15 years after inarching, showing position X at which section, photographed and shown in Fig. 4, was taken.

PLATE IV

FIG. 6.

Plan of excavated root system of Grenadier on Northern Spy ten years after inarching with three M.XVI rootstocks into the trunk (Tree 1). Black roots indicate Northern Spy root system, the remainder are M.XVI roots. Circles at root endings show their vertical descent into rock. Marginal rulings indicate half-metre distances.

PLATE V

FIG. 7.

Plan of excavated root system of Grenadier on Malling Crab H ten years after inarching with three M.XVI rootstocks into the trunk (Tree 7). Black roots indicate Malling Crab H root system, the remainder are M.XVI roots.

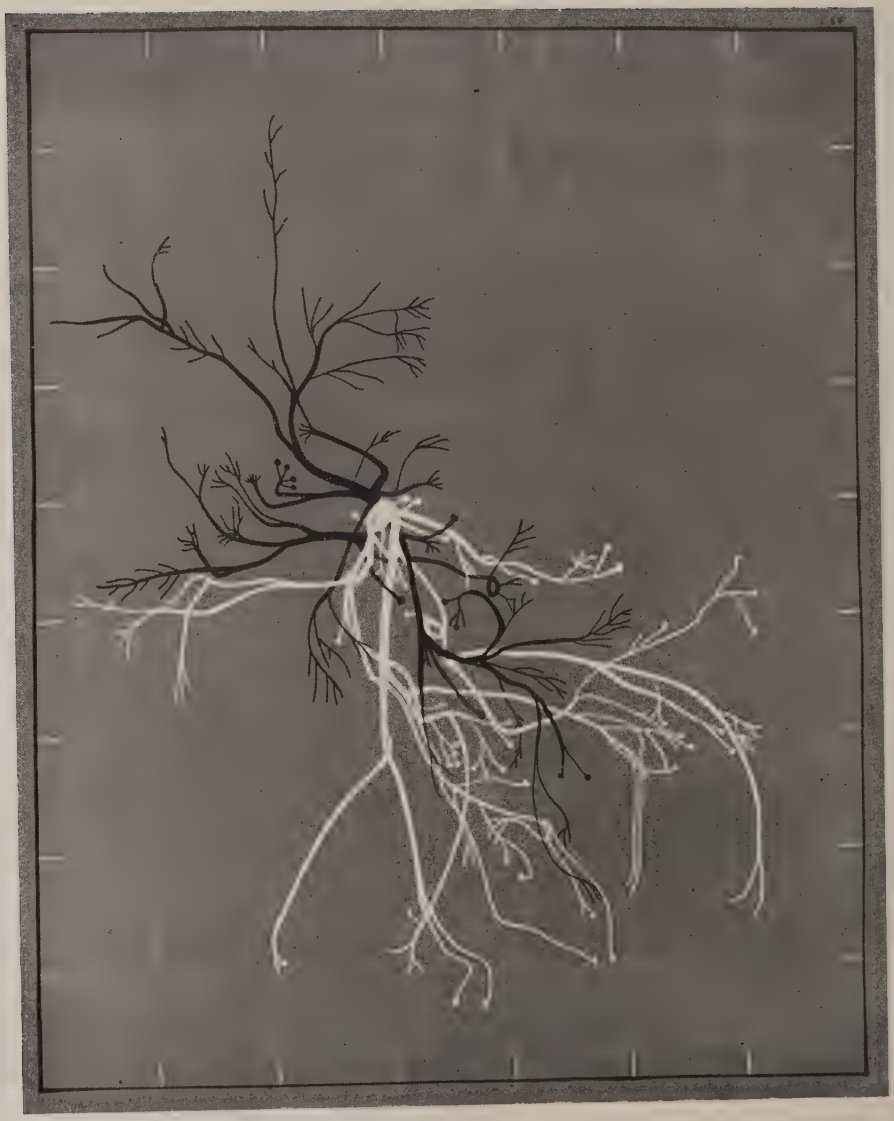

FIG. 8.

Plan of excavated root system of Grenadier on Malling Crab H fifteen years after inarching directly into a primary branch with one M.XVI rootstock (Tree 3). Black roots indicate Malling Crab H root system.

The growth made by trees on Northern Spy inarched with M.XVI rootstocks was considerably better than that of the control trees (Table I). Excavation of the root systems of two of these inarched trees (Trees 1 and 2), however, showed that, contrary to expectations, the root systems of the inarches were relatively restricted. Examination of the root depths showed that these inarches sent down many vertical roots which extended into the rock and it seems likely, therefore, that these deep roots assisted the extensive but shallow root system of the Northern Spy rootstock by penetrating the damp B horizon characteristic of the Malling soil series. It may well be that the roots of these inarches were forced downwards because the surface area was already occupied by the Northern Spy root system (Fig. 6). Conversely, with Tree 7, the M.XVI root systems were more extensive than that of the Malling Crab H (Fig. 7) and in this case, owing to the limited extent of the latter system, the M.XVI roots had more ground for exploitation and so developed laterally.

SUMMARY

1. The conclusion of an investigation into the reinvigoration of Grenadier apple trees on Northern Spy and Malling Crab H rootstocks by the inarching of vigorous M.XVI rootstocks is reported.

2. Dye injection and pomological data have shown an effect of inarching which became progressively greater since the earlier report.

3. Sixteen years from inarching the invigorating effect of the inarched rootstocks was still distributed unevenly amongst the main branches, due to the positioning of the inarches.

4. Results suggest that, to obtain a balanced top, the points of insertion of the inarches should be distributed evenly around the trunk and that they should be into tissues passing up between two main branches rather than into the middle of a main branch.

5. The root systems of four trees were excavated by the " Skeleton " method. Several natural root grafts were observed.

6. Although trees on Northern Spy inarched with M.XVI rootstocks were better than the non-inarched trees, root excavations showed that this was not due to an extensive inarch root system. The roots of the inarches were deep and it is suggested that they aided the extensive but shallow Northern Spy root system by penetrating a moist B soil horizon.

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THE EFFECT OF MALEIC HYDRAZIDE ON THE SPRING FROST RESISTANCE OF THE MALLING EXPLOIT RASPBERRY

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One method of avoiding damage to fruit plants by spring frosts is to delay their blossoming season.

Maleic hydrazide, a potent inhibitor of actively growing tissues (Leopold and Klein, 1951), causes cessation of the activity of terminal meristems and of elongation of internodes (Naylor and Davis, 1950). Depending on its concentration, it may cause a temporary suspension of stem elongation from the terminal bud, or it may kill the terminal bud and its adjacent tissues (Moore, 1950). McLeish (1953) has shown that uptake of maleic hydrazide depends on the growth rate of the plant, and that one of its effects when in the plant is to suppress mitosis in all actively growing tissues.

It has been tested as a blossom delayer on different fruit plants with varying degrees of success. Raspberries have shown a rather favourable reaction to it. The blossoming of black raspberries was delayed by spraying the plants with maleic hydrazide soon after " bud burst ", the length of the delay depending mainly upon the concentration of maleic hydrazide applied (White, 1950a and 1950b ; White and Kennard, 1950 ; White *et al.*, 1951 ; Kennard *et al.*, 1951). Less desirable effects were damage to young shoots and foliage, delay in the onset of ripening, malformation of the fruits, and reduction of the yield. With relatively low concentrations of maleic hydrazide there was considerable replacement of damaged shoots, the percentage of replaced shoots being inversely proportional to the concentration (Kennard *et al.*, 1951).

Applications of maleic hydrazide to red raspberries at later stages of development did not influence the time of flowering, but had the same adverse effects as those described above (Ferres, 1952).

In the experiments described below, the effect of an early application of maleic hydrazide on Malling Exploit red raspberry was investigated with respect to reduction of frost damage, both by delaying the time of blossoming and by increasing the frost resistance of the tissues.

Material and methods.

Twenty-four plants of Malling Exploit, grown in pots, were divided equally between the two treatments (*a*) plants sprayed with a solution of 750 p.p.m. maleic hydrazide (the diethanolamine salt) in 0·01 per cent. Aerosol, which was used as a wetter, and (*b*) the control plants, sprayed with a solution of 0·01 per cent. Aerosol only. The treatments were applied on 17th March, 1952, just after bud burst.

Four plants of each treatment were used in each of three experiments. The plants used in Experiment 1 were not frozen. They formed a basis for comparison

of the behaviour of those used in Experiments 2 and 3, which were subjected to controlled low temperatures in the frost laboratory, as described for black currant bushes in pots (Modlibowska and Ruxton, 1953).

The records made included (*a*) the stage of development of individual racemes at the time of spraying, (*b*) the stage of development of racemes at the time of freezing at the " green bud " and " open flower " stages, respectively, (*c*) the frost damage following freezing, (*d*) the production of secondary racemes, (*e*) the crop, and (*f*) new cane growth. Dead and broken racemes were also recorded.

The figures in the Tables are means of four plants, except for the control plants in Experiment 1. As one control plant died, the figures for this group are the means of three plants.

The categories used for recording the stage of development on 17th March, when the treatments were applied, and just after bud burst, were :

0—buds dormant,
1—buds burst,
2—part of the first leaf recognizable,
3—1 to 2 leaves separated,
4—3 leaves separated.

In the second record of the stage of development, made at the " green bud " stage, the following categories were used :

NV—flower buds not yet visible,
NS—flower buds visible but not separated,
S—flower buds separated.

When the plants were at the " open flower " stage a third record of the stage of development of racemes was made, and the racemes were divided into the two categories " not flowering " and " flowering ".

The crop was picked twice a week as ripening proceeded, both the number and the weight of normal and misshapen fruit being recorded.

New canes were counted and their length measured.

RESULTS.

The effect of maleic hydrazide on development of lateral shoots.

Experiment 1. The records of the stage of development of the plants, 38 days after treatments were applied, show that maleic hydrazide had no apparent effect on the dormant buds, but delayed the development of shoots at the later stages (Table I). The delay amounted to about two weeks. Whilst most of the racemes on the control plants had their buds separated (" S "), the racemes on the sprayed plants were more evenly divided between the three stages recorded, " NV ", " NS ", and " S ". There was a greater percentage of dead racemes on the sprayed plants, particularly those sprayed at the later stages, 3 and 4, than on the controls. On the sprayed plants, the dead shoots were always replaced by secondary laterals which grew from directly below them. No secondary shoots grew below dead shoots on the control plants, or below dormant buds or broken shoots in either treatment.

The time of flowering was delayed by the maleic hydrazide treatment (Table II), and represented about seven days delay in blossoming.

TABLE I.

Effect of maleic hydrazide on development of laterals, 38 days after spraying.

Stage of development at spraying	Treatment	Number racemes per plant	Stage of development, 38 days after spraying					Replacement of dead shoots %
			NV %	NS %	S %	Dead %	Broken %	
0	Sprayed	**14·8**	**54·1**	**8·5**	**3·4**	**27·2**	**6·8**	**6·3**
	Controls	10·3	74·2	9·7	3·2	12·9	nil	nil
1	Sprayed	**44·0**	**19·4**	**35·8**	**30·0**	**9·1**	**5·7**	**100**
	Controls	36·7	31·8	14·6	50·9	0·9	1·8	nil
2	Sprayed	**21·5**	**19·6**	**40·8**	**23·3**	**16·3**	nil	**100**
	Controls	23·0	4·3	13·1	81·2	nil	1·4	—
3	Sprayed	**5·8**	**8·7**	**34·8**	**26·1**	**26·1**	**4·3**	**100**
	Controls	11·7	nil	nil	97·1	nil	2·9	—
4	Sprayed	**1·3**	nil	**80·0**	nil	**20·0**	nil	**100**
	Controls	2·0	16·7	nil	83·3	nil	nil	—
All stages	Sprayed	**87·4**	**24·4**	**32·9**	**23·2**	**15·2**	**4·3**	**71·8**
	Controls	83·7	24·7	11·2	60·5	2·0	1·6	nil

TABLE II.

Effect of maleic hydrazide on time of flowering, 65 days after spraying.

Stage of development at spraying	Sprayed		Controls	
	Number racemes per plant	Racemes bearing open flowers. %	Number racemes per plant	Racemes bearing open flowers. %
0	7·8	3·2	5·3	—
1	32·2	20·9	27·7	62·8
2	16·0	7·8	20·3	83·7
3	3·8	6·7	10·3	100
4	0·2	—	1·7	100
All stages	60·0	14·2	65·3	71·0

TABLE III.

Effect of maleic hydrazide on yield.

Treatment	Number of racemes per plant	Fruiting racemes %	Number of flowers per plant	Fruit set %	Misshapen fruit %	Fruits on secondary racemes %	Total crop per plant (gm.)
Sprayed	55·8	24·8	162·5	67·8	6·8	34·5	354·7
Controls	55·7	71·4	235·8	63·0	3·0	—	461·6

Maleic hydrazide delayed fruit ripening by one week on the sprayed canes and prolonged the picking season (Fig. 1). The fruit ripened more slowly and reached the end of the " commercial " picking season three weeks later on the sprayed plants than on the controls.

The total weight of the crop per plant was about 23 per cent. lower on the sprayed plants than on the controls (Table III). The mean number of racemes per plant (excluding broken, dead before freezing, and secondary ones) was the same

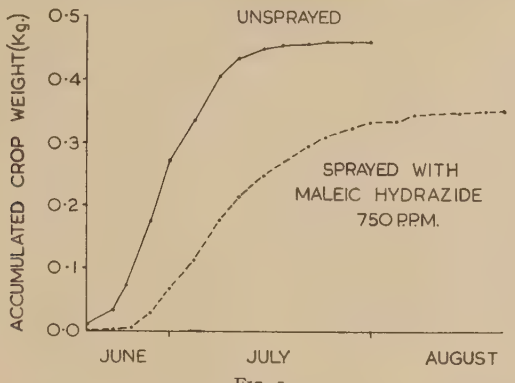

FIG. 1.

Effect of maleic hydrazide on time of ripening and on yield.

for both treatments, but only about a quarter of them bore fruit on the sprayed plants compared with nearly three-quarters on the controls. As a result, the mean number of flowers per plant was lower on the sprayed plants than on the controls by about a third, but a slightly greater percentage of them set fruit. About a third of the ripe fruits on the sprayed canes was borne on secondary racemes. There was about twice the proportion of misshapen fruits on the sprayed plants as on the controls, but in both treatments the percentage was low.

The production of new canes was not checked by the spray, in fact the sprayed plants produced an average of 10 new canes, compared with 6·7 produced by the controls and the mean length was about the same in both groups (75·0 cm. and 76·1 cm. respectively).

The effect of maleic hydrazide on the incidence of frost damage.

Experiment 2. Plants frozen at the " green bud " stage. At the " green bud " stage four plants from each treatment were subjected to low temperature conditions [—3·1° C. (26·4° F.) for 45 mins.] in the frost laboratory, 36 days after application of the spray treatments. Records of the stage of development of racemes (in the categories " NV ", " NS ", and " S ") were made two days after freezing, i.e. at the same time as records were made in Experiment 1. The frost damage was recorded early in June when the buds had opened.

The results, Table IV, show that at the date of freezing the majority of the racemes on the control plants were at the most advanced stage, " S ", but on the

plants sprayed with maleic hydrazide they were more evenly divided between the three stages.

There was more frost damage to the racemes on the sprayed plants than to those on the controls (Table IV). In both treatments racemes at the earliest stage (" NS ")

TABLE IV.

Effect of maleic hydrazide on frost damage at " green bud " stage. [All plants subjected to —3·1° C. (26·4° F.) for 45 mins.]

Stage of development of racemes at freezing	Treatment	Racemes per plant		Dead racemes %	Killed buds %
		Number	Percentage at each stage		
NV	Sprayed	**23·3**	**32·8**	**82·5**	**84·5**
	Controls	14·3	22·8	84·1	10·2
NS	Sprayed	**27·3**	**38·6**	**51·8**	**65·2**
	Controls	9·8	15·6	23·1	34·6
S	Sprayed	**20·3**	**28·6**	**4·9**	**43·5**
	Controls	38·5	61·6	nil	63·8
All stages	Sprayed	**70·8**	**100**	**48·1**	**51·9**
	Controls	62·5	100	22·8	55·2

were more heavily damaged than those at the later stages of development. The latter were more adversely affected by maleic hydrazide. Comparison with Table I indicates the magnitude of the difference between the damage due to the low temperature conditions and that from other causes, including the spray treatments.

There was slightly less damage to buds on the sprayed plants than to those on the controls. Whilst on the controls the youngest buds were less damaged than the older ones, in accordance with general experience (Ruxton and Modlibowska, 1954), the reverse was the case on the sprayed plants.

Although there were more racemes per plant on the sprayed canes than on the controls (Table V), excluding broken, dead (before freezing), and secondary racemes,

TABLE V.

Effect of maleic hydrazide on yield of plants frozen at the " green bud " stage.

Treatment	Number of racemes per plant	Fruiting racemes %	Number of flowers per plant	Fruit set %	Misshapen fruit %	Fruits on secondary racemes %	Total crop per plant (gm.)
Sprayed	70·75	49·5	156·25	29·8	11·3	61·8	225·1
Controls	62·5	76·3	325·5	47·1	2·8	—	327·1

fewer of them bore fruit. There were also fewer flowers per plant and a smaller percentage of fruit set on the sprayed canes than on the controls. In this Table the figures do not include records of fruit on the secondary racemes, except in the mean

weight of fruit per plant. The total crop on the sprayed plants was about 69 per cent. of that on the controls, being slightly less, by proportion, than that on the unfrozen sprayed plants (Experiment 1, Table III). More than 60 per cent. of the fruit on the sprayed plants was produced on secondary racemes. The proportion of misshapen fruit on the sprayed plants was about four times that on the controls, and nearly twice that on the unfrozen sprayed plants of Experiment 1 (Table III). On both the sprayed and control plants, however, it was again relatively small.

As in Experiment 1, spraying the canes with maleic hydrazide delayed fruit ripening and prolonged the picking season. Exposure to low temperature had no effect on the time of onset of ripening in either treatment, but the picking season was shorter on the sprayed canes and longer on the controls than it was on the corresponding unfrozen plants in Experiment 1.

Experiment 3. Plants frozen at the " open flower " stage. The remaining four plants of each treatment were exposed at the " open flower " stage to low temperature conditions in the laboratory [—2·0° C. (28·4° F.) for 2 mins.] on 20th May, 65 days after application of the spray treatments.

Records of frost damage to open flowers and of the stage of development were made on the day following the low temperature treatment. Further records of damage were made on 6th June when the buds had opened.

The results (Table VI) show that whilst nearly half of the racemes on the control plants bore open flowers at the time of freezing, only 4 per cent. of those on the plants

TABLE VI.

Effect of maleic hydrazide on frost damage at " open flower " stage. [All plants subjected to —2·0° C. (28·4° F.) for 2 mins.]

Stage of development of racemes at freezing	Treatment	Number racemes per plant	Percentage of racemes at each stage	Dead racemes %	Buds		Flowers	
					Number per plant	Killed %	Number per plant	Killed %
Not flowering	Sprayed	**57·3**	**95·9**	**67·8**	**85·5**	**12·6**	nil	—
	Controls	32·5	53·8	66·9	32·3	34·9	nil	—
Flowering	Sprayed	**2·5**	**4·1**	**20·0**	**2·5**	**40·0**	**10·0**	**50·0**
	Controls	28·0	46·2	9·8	52·3	69·0	131·0	62·6
Both stages	Sprayed	**59·8**	—	**65·7**	**88·0**	**13·3**	**10·0**	**50·0**
	Controls	60·5	—	40·7	84·5	56·0	131·0	62·6

sprayed with maleic hydrazide had reached the flowering stage. There was more damage to both buds and open flowers on the control plants than there was to those on the sprayed plants. In both treatments open flowers and buds on the more advanced shoots were more damaged than buds on the later flowering shoots.

There was a similar number of racemes per plant in both treatments (Table VII), excluding secondary racemes, but as in the two previous experiments a smaller percentage of those on the plants sprayed with maleic hydrazide bore fruit as compared with those on the controls. There were fewer flowers but a greater percentage of fruit set on the sprayed plants than on the controls, excluding secondary racemes,

and the final crop (including that on secondary shoots) was about 73 per cent. of that on the controls. In this experiment only about a quarter of the crop on the sprayed canes was borne on secondary racemes. The percentage of misshapen fruits on the

TABLE VII.

Effect of maleic hydrazide on yield of plants frozen at " open flower " stage.

Treatment	Number of racemes per plant	Fruiting racemes %	Number of flowers per plant	Fruit set %	Misshapen fruit %	Fruits on secondary racemes %	Total crop per plant (gm.)
Sprayed	59·8	34·3	143·8	51·0	6·5	24·2	222·6
Controls	60·5	59·3	396·3	35·0	2·8	—	304·8

sprayed plants was about twice that on the controls, as in Experiment 1 (Table III).

The onset of ripening was delayed and the picking season prolonged by spraying the plants with maleic hydrazide. Exposure to low temperature only slightly delayed the onset of ripening in each treatment, had no effect on the length of the picking season of the control plants but shortened that of the sprayed plants.

DISCUSSION.

Maleic hydrazide sprayed on canes of Malling Exploit raspberry at the " bud burst " stage was most effective on actively growing buds in which the young leaves were separated and expanding, thus presenting a larger absorbing surface than the earlier stages. Dormant buds when affected were killed, but generally there was no effect at this stage. These results would suggest that actively growing tissues, in which the cell walls are relatively immature and permeable, are the most susceptible to the effects of maleic hydrazide. Some young shoots at each stage of development following " bud burst " were killed by maleic hydrazide, those just bursting having the lowest mortality rate.

Flowering was delayed by the treatment. Consequently, there was less damage on the sprayed canes than on the controls when the plants were exposed to low temperature at the " open flower " stage, since open flowers are more susceptible to damage than buds. Racemes which had just burst their buds at the time of spraying were the ones least delayed in flowering.

The inhibitory effects of maleic hydrazide wore off as the surviving racemes developed, as was shown by the smaller delay in the time of flowering than in the early development of racemes. The effect on the frost resistance of the buds and racemes depended on the degree of inhibition. With strong inhibition and the consequent damaging effect, even to the point of killing the buds, the tissues became more susceptible to frost. There was a point, however, where a lesser degree of inhibition was associated with an increase of frost resistance, as shown by buds on the more developed racemes (Table IV) and on plants just coming into blossom (Table VI). These results suggest that the effect of maleic hydrazide on many of the bursting buds which were not too strongly inhibited was one of hardening, and that buds which recovered from a stronger initial inhibition carried a residual hardening effect.

The inhibiting effects were very localized in the plant, as was shown by the production of secondary laterals in the same axil as, and below, dead racemes. Replacement of dead laterals is also common in the field, following early frosts at the time of " bud burst ".

The net effect of maleic hydrazide was, however, harmful. In spite of the decreased frost damage at the later stages of development and the replacement of killed racemes by secondary ones, the total crop was smaller on the sprayed plants than on the controls. Ripening was delayed and the picking season prolonged.

SUMMARY.

Malling Exploit raspberry plants were sprayed at " bud burst " with 750 p.p.m. maleic hydrazide and subjected to low temperature conditions at the " green bud " and the " open flower " stages, respectively.

The maleic hydrazide delayed the growth of many buds, particularly those most advanced at the time of spraying. Some buds were killed, however, and secondary ones which replaced most of these did not compensate for the initial damage.

Three effects of maleic hydrazide on frost damage were found, viz. (1) Frost damage was increased where there was strong inhibition of growth. (2) A certain degree of frost resistance was induced in buds which were not too strongly inhibited. (3) The delay in blossoming tended to reduce frost damage.

The net effect of spraying with maleic hydrazide was harmful as it reduced the total crop.

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THE EFFECT OF SOIL CARBON DIOXIDE ON MANGANESE UPTAKE AND GROWTH OF THE POTATO

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THE manganese content of plants is very variable, and Erkama (1950) has claimed that its concentration varies more than that of other heavy metals. Some of the factors influencing the level of manganese in the plant have been discussed by Goodall and Gregory (1947).

Bortner (1935), Somers and Shive (1942) and Bennett (1945) have shown that manganese concentration in plants becomes greater with increase in manganese concentration in the culture solution.

In the soil this relationship is complicated by the so-called " availability " of the manganese to the plant, and most cases of manganese deficiency in the field are due to the insufficient availability of the element to the plant rather than to its absence from the soil.

The factors affecting the availability of manganese in the soil have been reviewed by many workers (Mann, 1930 ; Bortner, 1935 ; Swanback, 1939 ; Timonin, 1946 ; Berger and Gerloff, 1947 ; and Leeper, 1947, 1952). Bolas and Portsmouth (1948) noted the patchy distribution of manganese deficiency symptoms in potatoes growing in a calcareous loam on a lake-bed delta at East Malling. When this soil was transferred to 10-inch pots coated internally with bitumen, no deficiency symptoms appeared on the plants. It was suggested that the carbon dioxide content of the soil might be related to the availability of manganese.

In support of this hypothesis, Bolas and Portsmouth (1948) described an experiment in which weighed amounts of the manganese-deficient soil were extracted for 48 hours with varying amounts of water saturated with carbon dioxide. They found that with a very small pH change, a considerable amount of manganese was extracted. Accordingly it was decided to test this hypothesis on a larger scale by means of soil cultures.

CONTROL OF CARBON DIOXIDE IN SOIL CULTURES.

Materials and methods.

Majestic seed potatoes (Scotch certified) were used, graded between the limits of 40-70 g. per tuber. Ninety 10-inch pots were set up and one tuber was planted in each pot at the beginning of May, 1949. The pots were crocked with a 2-inch layer of washed flints and filled with soil from the lake-bed which was known to produce manganese deficiency in potato plants grown *in situ*. The plants were watered, as

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required, with water from the stream that supplied the lake-bed. The water was of pH 8 and contained less than 1 p.p.m. manganese.

Two series of pots were used : (1) untreated control series, (2) similar pots which had received three internal coats of bitumen paint. The object of this coating was to prevent any manganese being absorbed by the plant from the pot walls, and to reduce gaseous diffusion.

Three treatments, starting on 14th June, 1949, were given in each series :

1. Soil continuously aerated by drawing air through the pots at a rate of about 1 litre per minute per pot. (The air was drawn through, not blown, to avoid oil spray contamination from the pump.)
2. Normal pot culture.
3. Carbon dioxide from a cylinder was passed at the rate of about ½ litre per minute through each pot for 10 minutes daily.

Distribution system for carbon dioxide and air.

Carbon dioxide was passed into the bottom of each pot, the remaining holes of the pots being plugged with corks. A " bubbler " filled with a 50 per cent. mixture of glycerine and water showed that each pot was receiving its carbon dioxide. In the aerated series a similar set-up was used and air was withdrawn from the bottom of each pot.

Experimental observations.

Carbon dioxide determinations. Carbon dioxide determinations of the soil air were made with a Haldane apparatus on three occasions during the season. Usually two duplicate estimations were made on each treatment. The mean values are given in Table I.

TABLE I.

Per cent. carbon dioxide content of soil cultures. Carbon dioxide given 23 hours before analysis.

Uncoated pots			Coated pots		
Aerated	Control	CO_2 supplied	Aerated	Control	CO_2 supplied
0·1±·02	0·4±·04	0·8±·17	0·2±·06	0·5±·06	1·5±·27

Five replicates in each treatment.

The treatments were effective in maintaining a wide range of carbon dioxide in the soil. Aeration greatly reduced the carbon dioxide content below that of the control pots but no significant difference was found between the coated and uncoated pots.

Hiltner (1924) claimed that increased carbon dioxide in the atmosphere prevented the appearance of manganese deficiency symptoms. Analyses of the air above the plants showed that carbon dioxide diffused rapidly through the atmosphere of the glasshouse, and there appeared to be no evidence of local accumulations of carbon dioxide in the air surrounding the carbon dioxide-treated plants.

During the passage of carbon dioxide through the pots, a slight temporary wilting of the plants was occasionally produced. This wilting did not appear to be

due to any cooling effect of the carbon dioxide, as only in two cases did thermometers in the soil of the pots show any fall in temperature during the passage of the gas. (2–4° C.)

pH determinations. Various methods of pH determination were tried including indicator, quinhydrone electrode and the glass electrode, of which the latter was the most satisfactory.

The pH values obtained with a B.D.H. comparator at the beginning of August are shown below.

	Uncoated pots	*Coated pots*
Aerated	8·2	8·2
Control	8·2	8·1
CO_2 supplied	8·0	7·9

The glass electrode determinations of pH at the end of August were as follows :

	Uncoated pots	*Coated pots*
Aerated	8·4	8·1
Control	8·2	8·0
CO_2 supplied	7·4	7·9

It will be seen that there is some small negative correlation between carbon dioxide and pH values ; the acidity may thus have contributed to the effects of carbon dioxide supply.

Growth measurements. Growth measurements of all the plants (height of stem, number of leaves and number of side shoots) were carried out at weekly intervals from 21st June to 30th August.

Records of fresh and dry weights of leaves, buds, stems, roots and tubers were kept, one plant taken at random from each treatment being sampled each week from 5th July to 30th August. Manganese analyses were carried out on each of the dried samples, using the method of Ruck and Bolas (1954).

Results of carbon dioxide experiment.

Dry weight determination.

Table II gives the cumulative dry weights of the samples taken on the various occasions. The effects of the carbon dioxide treatments on the dry weight of the

Table II.

Effect of CO_2 content of the soil air on dry weight (g.).

Plant parts	High CO_2		Medium CO_2		Low CO_2	
	Dry weight	% total dry weight	Dry weight	% total dry weight	Dry weight	% total dry weight
Leaves ..	279	29·7	265	22·8	268	24·7
Stems ..	115	12·2	70	6·0	77	7·1
Buds ..	9	0·9	8	0·7	7	0·7
Roots ..	70	7·4	57	4·9	58	5·3
Tubers ..	467	49·8	763	65·6	676	62·3
Total wt.	940		1,163		1,086	

plant organs are shown, together with the percentage of total weight of the plants contributed by these parts. For convenience in presentation, the treatments are reduced to three, on the basis of the carbon dioxide content of the soil, samples from the coated and uncoated pots in each treatment being combined.

It will be observed that the total weight of the plants in soil of high carbon dioxide content is less than that of those of the other treatments. An analysis of variance made on the dry weights throughout the experimental period showed that this was significant at the 0·05 per cent. level.

The outstanding effect of the treatments is in the difference in relative weights of the plant parts. The plants of the high carbon dioxide series have a significantly greater weight of stems ($P<0·01$), whereas there is no significant difference between the weights of leaves and roots in the three treatments. In contrast, the tuber weights in the high carbon dioxide treatment are reduced by approximately 60 per cent. ($P<0·01$).

Tuber number.

The mean number of tubers formed during the experimental period is given below.

High CO_2 11·6 Medium CO_2 9·6 Low CO_2 8·1

Sig. diff. ($P=0·05$)=2·5

The mean number of tubers formed in the high carbon dioxide series is greater ($P<0·05$) than that in the low carbon dioxide treatment, whereas the mean tuber weight is less. It thus appears that the high carbon dioxide soil content has reduced translocation to the tubers.

Growth measurements.

The mean heights of the plants at each sampling time at the three carbon dioxide levels are shown graphically in Fig. 1, the first measurements being taken approximately four weeks after planting. An analysis of variance showed that the plants of the high carbon dioxide series were significantly taller ($P<0·01$) than those of the other treatments. This effect on height was not observed until the fifth sampling period (12th July), approximately four weeks from treatment with carbon dioxide.

The mean heights of the plants (cm.) in each treatment during the experimental period are given below (Table III).

TABLE III.

Mean heights of plants (cm.). (Six carbon dioxide levels.)

	Uncoated pots	Coated pots
Aerated	27·3	27·1
Control	23·6	32·9
Treated CO_2 ..	31·7	34·8
	(Sig. diff. ($P=0·05$)=3·8)	

When all treatments are combined, plants from the coated pots were significantly taller than those from the uncoated pots ($P<0·01$). Whatever may be the cause

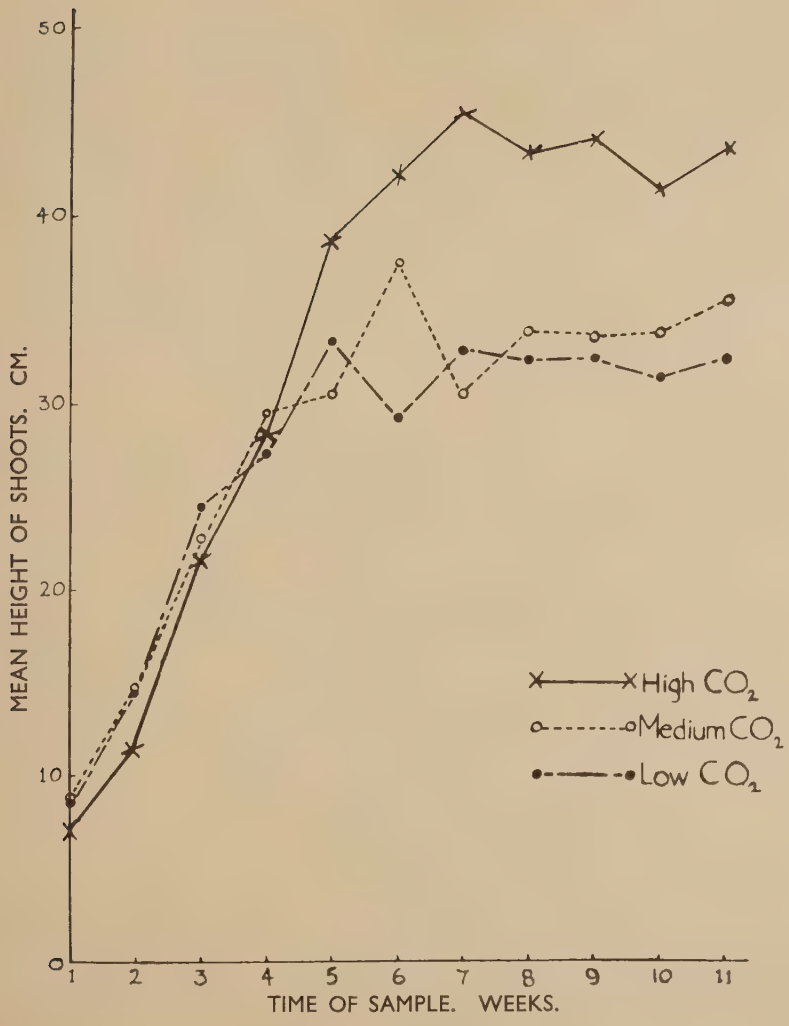

Fig. 1.

Mean heights of plants at weekly intervals (three CO_2 levels). (Cm.)

of the difference in heights of the uncoated and coated pot plants, it is of interest to note that this difference does not exist in the aerated series.

Flower production.

The high carbon dioxide treatment also had a significant effect on the number of flowers produced ($P<0.05$). Flowers of the plants not receiving carbon dioxide fell off before opening, whilst many of the flowers of the carbon dioxide plants opened and eventually produced fruits.

No symptoms of manganese deficiency were observed in pot-grown potatoes in any of the treatments, which is in marked contrast to the results obtained with the same soil in the field. The carbon dioxide-treated plants appeared more vigorous than the others and the onset of senescence was delayed, as judged by the persistence of the green colour of the leaves. These, later, were destroyed by blight (*Phytophthora infestans* (Mont.) de Bary), after the control plants were senescent and, accordingly, the ultimate behaviour of the plants in soil of high carbon dioxide content could not be observed. This difference in development must be borne in mind when the manganese uptake of the plant is considered.

Manganese content of plants.

The mean manganese contents of the various plant organs in the three treatments are given in Table IV. The results show the concentration (p.p.m.) in the dry matter, total manganese content (μg) of the whole plant and its parts and percentage of total manganese present in the various plant organs.

TABLE IV.

Effect of CO_2 on manganese content of the various plant organs.

	High CO_2			Medium CO_2			Low CO_2		
	p.p.m.	μg	% Mn	p.p.m.	μg	% Mn	p.p.m.	μg	% Mn
Leaves ..	18·8	5,230	65·7	15·4	4,092	58·3	15·5	4,161	56·4
Stems ..	3·9	451	5·7	4·1	289	4·1	4·0	306	4·1
Buds ..	15·5	136	1·7	13·9	107	1·5	15·1	107	1·5
Roots ..	9·0	625	7·9	10·1	575	8·2	9·6	553	7·5
Tubers ..	3·2	1,515	19·0	2·6	1,950	29·8	3·3	2,254	30·5
Whole plant ..	8·5	7,957		6·0	7,013		6·3	7,380	

It was found that (1) manganese concentration in the plants of the high carbon dioxide treatment was 33 per cent. higher than in the other two treatments ($P<0.01$). (2) There was no significant difference between the total amounts of manganese (μg) per plant in the three treatments. (3) The manganese in the plant is concentrated in the leaves and buds; the concentration in the tubers is particularly low.

The relative concentrations in the various organs, means of all treatments, are as follows: leaves 5·5, stems 1·3, buds 4·9, roots 3·2, tubers 1·0.

Approximately 50 per cent. of the total manganese in the plant is concentrated in the leaves, indicating some special metabolic significance of the element in these

organs. Many other workers have confirmed the finding that manganese concentration is highest in the leaves (Kelley, 1912; Jones and Bullis, 1921; Bertrand and Rosenblatt, 1922; Remington and Shiver, 1930; and Steiner, 1943). The high concentration in the buds shows that manganese accumulation occurs very early in the life of the leaf. Whereas concentrations of manganese in the mature leaf may be due to transport in the transpiration stream, the high concentration in the buds cannot be due to this cause and manganese must be actively translocated to the meristematic regions of the plant.

The manganese concentration of the buds of tubers compared with that of slices of tissues beneath the skin from various parts of the tuber are shown below.

Buds	*Peeled slices of tuber*
11·9±0·61 p.p.m.	4·9±0·39 p.p.m.

Six replicates in each sample.

It will be observed that manganese is concentrated in the buds of the tuber. This confirms the findings of McHargue (1914, 1926), Bishop (1928) and Glasscock and Wain (1940) who have shown that manganese is concentrated in the most active metabolic regions of the plant.

DISCUSSION.

The interpretation of the effect of carbon dioxide on the uptake of manganese by the plant is complicated by the effect of the treatments on the size and rate of development of the plants.

There appears to have been no difference in total manganese uptake between the plants receiving the three treatments, but those with the high carbon dioxide had less total dry matter than the others, and so showed a higher concentration of manganese.

Owing to the incidence of potato blight (*Phytophthora infestans* (Mont.) de Bary), the plants of the high carbon dioxide series did not reach maturity, so the final manganese content of these plants could not be ascertained. Thus, although carbon dioxide has delayed senescence in the experiment, there is no evidence of any direct effect of carbon dioxide on manganese uptake.

The most marked effect of the carbon dioxide treatment was on the height of the plants, the soil of high carbon dioxide content producing much taller plants. The behaviour of the plants in the uncoated and in the coated pots confirms this result, the control series in the coated pots resembling the high carbon dioxide treatments, while in the aerated pots the bitumen coating had no effect on height.

This stimulating effect of carbon dioxide has been noted by Mer and Richards (1950) who found an increase in length of mesocotyls of etiolated oat seedlings in high carbon dioxide concentration in the dark, accompanied, however, by a decrease in length of coleoptiles, and by Livingston and Beall (1934) who passed carbon dioxide gas continuously through soil in pots containing six different species of plants. They found that in general the carbon dioxide-treated plants were more vigorous than the controls, as measured by increase in shoot elongation, and suggested that the effect may be due to (1) the possibility of increased carbon dioxide uptake by the roots, the carbon dioxide becoming available for photosynthesis, (2) the carbon

dioxide making soil nutrients more readily available and influencing the microflora of the soil.

In the potato, this effect of carbon dioxide on vigour and size of the plant is complicated by its effect on the formation of tubers, the plants in soil of low carbon dioxide content having approximately 60 per cent. by weight more tubers than those in the high carbon dioxide treatment.

The first suggestion of Livingston and Beall that soil carbon dioxide is taken up directly by the roots and becomes available for photosynthesis is, however, not supported by our experiments, as in fact the total growth of the plants of the high carbon dioxide treatment over the experimental period has been significantly less. It appears that the carbon dioxide effect is an indirect one, probably due to interference with translocation of carbohydrates from the aerial portions of the plants to the tubers. This agrees with the views of Curtis (1935), Bonner and Galston (1952) and others who consider that translocation is closely associated with respiration, and is reduced by chemical inhibitors and lack of oxygen.

Aeration of the soil did not produce any marked effect on the form of manganese or on its uptake by the plants, and no manganese deficiency symptoms were produced by any of the treatments. Thus it may be concluded that the difference in behaviour of the plants in pots from that of those grown in the same soil in the field cannot be accounted for by the hypothesis of high carbon dioxide content.

SUMMARY.

1. To investigate the effect of soil carbon dioxide on uptake of manganese and on growth, potato plants were grown in a "manganese-deficient" soil in 10-inch pots. Some pots received extra carbon dioxide, others served as controls, and a third series was aerated. These treatments were repeated in pots that had been coated internally with bitumen. A wide range of carbon dioxide content of the soil was obtained.

2. The outstanding effect of the high carbon dioxide content was on the form of the plant. The plants receiving carbon dioxide were considerably taller, whereas the tuber weights were reduced by approximately 60 per cent. compared with those in the other treatments. This reduction in translocation may be related to the inhibiting effect of carbon dioxide on respiration.

3. Plants from the coated pots, except those receiving aeration, were significantly taller than those from the uncoated pots.

4. In the plants with high carbon dioxide concentration in the soil, there is some evidence that senescence was delayed. The experiment had to be terminated prematurely owing to attack by potato blight so that the total manganese content at maturity of these plants could not be ascertained.

5. The manganese concentration of the plants of the high carbon dioxide treatment was 33 per cent. higher than in the other two treatments ($P<0{\cdot}01$) but there was no significant difference between total amounts of manganese per plant in the three treatments. The increase in concentration can be accounted for by the smaller weight of the plants of the high carbon dioxide series and there is therefore no evidence for any direct effect of carbon dioxide on manganese uptake.

6. Manganese in the plant was found to be concentrated in the leaves and buds, the content of the stems and tubers being very low, and that of roots intermediate.

7. The great difference of the plant behaviour in the soil used, comparing plants in pots with those *in situ*, cannot be explained by the carbon dioxide hypothesis, as aeration of the soil failed to induce symptoms of manganese deficiency.

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MANURIAL EXPERIMENTS WITH FRUIT

I. THE EFFECT OF LONG-TERM MANURIAL TREATMENTS ON SOIL FERTILITY AND ON THE GROWTH, YIELD AND LEAF NUTRIENT STATUS OF STRAWBERRY, *VAR.* CLIMAX.

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In 1924, two long-term manurial experiments on strawberries were laid down at Long Ashton. The first experiment was designed to investigate the effect of various commercial manurial treatments on strawberry plants grown continuously on the same plots for several plantings. The results of this experiment have been described by Knight and Wallace (2) and Wallace and Vaidya (6). The first paper dealt with the effect of treatments on the chemical composition of the fruit and the second paper with vigour of growth and crop yields. The second field experiment was designed to investigate the comparative effects of F.Y.M. and complete artificials, and the omission of N, P and K respectively, on the growth and yield of strawberries. Owing to the deleterious effects of pests and virus diseases the early trials with strawberries were unsuccessful and have not been reported. The present phase started in 1950, the object being to investigate the effect of treatments on the growth, yield, quality and leaf nutrient status of strawberries with particular emphasis on leaf analysis. The effect of these treatments on fruit quality has been described by Kieser, Pollard and Timberlake (1).

The results of the present experiment illustrate the relationship between leaf nutrient status, deficiency symptoms and yield of fruit, and indicate approximately the most satisfactory level for certain plant nutrients at specific stages in the growth of the strawberry. They show the high phosphate feeding capacity of the variety Climax and the lack of response to omission of applied phosphate, the importance of potassium for good quality and heavy yields, and the relatively low nitrogen requirement of the strawberry plant.

Literature.

The literature dealing with manurial experiments on strawberries up to 1938 has been reviewed by Knight and Wallace (2) and Wallace and Vaidya (6). In their own experiments, dealing with the influence of organics and complete inorganics on the yield and chemical composition of the fruit, these authors found the treatments to have a significant effect. A close correlation was found between the vigour of the plants and the yield of fruit from them. Plants receiving farmyard manure were the most vigorous and produced the largest crops, and those growing under conditions of potassium deficiency proved the lightest croppers and gave the smallest fruit. Treatments also had an effect upon the chemical composition of the fruits. The nitrogen content of the fruits decreased over the picking season and was highest in those fruits from plots which had received inorganic fertilizers. There was a negative correlation between nitrogen content and acidity and between nitrogen content and

total sugars. The acid content of the fruits was lowest on plots receiving no potassium. The authors state that the results of the investigation support the field observation that potassium deficiency is an important factor in the problem of the manurial treatment of strawberries and show that the application of potassic fertilizers is clearly reflected in the chemical composition of the fruits.

Kieser *et al.* (1), using sub-samples of fruit from the present experiment, found that in the first two cropping seasons (1951-52) plots receiving N and NP treatments (i.e. those without K) gave fruits with the lowest ascorbic acid contents, and lowest titratable acidities, and obtained the lowest scores for flavour. Total sugar was lowest in fruit from plots receiving NP; all other treatments gave higher sugar values in both seasons. In 1951 the pectin content of fruit from plots receiving F.Y.M., NPK, NK and PK was higher than that from plots receiving NP. Treatment with N only gave an intermediate value.

The authors concluded that omission of potassium resulted in a lowering of both yield and quality, both effects being accentuated by addition of phosphate. It was their opinion that fruit from the NP plots was always lacking in full flavour and aroma and was poor in colour.

Lineberry and Burkhart (3) grew two varieties of strawberry in nutrient solutions and studied the effect of treatments on the nutrient status of leaves and fruit. Analysis of dormant plants showed that there was a considerable accumulation of potassium in the roots as compared with that in leaves and crowns. Analysis of the fruit showed a relatively high concentration of potassium, which increased with nitrogen deficiency. Soluble phosphate accumulated in potassium-deficient foliage and fruit. The accumulation of soluble phosphate in nitrogen-deficient leaves was very marked. The authors concluded that the use of foliar analysis as an index of nutrient condition might be practicable.

In a later paper Lineberry *et al.* (4) described the effect of manurial treatments; they compared various forms of nitrogen in combination with phosphate and potassium, on the yield and leaf nutrient status of strawberry plants growing in a soil with an original pH of 4·6. Nitrogen alone, or in the presence of potassium, produced little extra growth. Addition of 160 lb. P_2O_5 per acre increased fresh weight of leaves by 70 per cent. and total fresh weight of the whole plant by 320 per cent. In complete fertilizers the lower rate of nitrogen gave higher yields than heavier dressings. The authors suggest 60 to 100 lb. N per acre as being sufficient. Source of nitrogen had no significant effect. The addition of potassium had no consistent effect on yields but no potassium deficiency symptoms developed in the leaves and the authors conclude this was due to high reserves of potassium in the runners at planting time. Fully expanded leaves were taken for chemical analysis in June. Leaves showing phosphorus deficiency symptoms at this stage contained 0·45 per cent. P_2O_5 as a percentage of dry matter. Leaves from plants receiving phosphate and showing no phosphorus deficiency symptoms contained 0·68 per cent. P_2O_5. Leaves containing 1·4 per cent. K_2O showed no potassium deficiency symptoms and did not respond to additions of potassium manures.

Experimental.

Site and soil.

The site is fairly level and open with a windbreak on the west side. Mechanical analysis of surface and subsoil (plots receiving no manurial treatment) from an

adjoining site, taken in 1932, together with some chemical data, are given in Table I.

Table I.

Soil analyses. Samples taken February, 1932. Analyses on air-dry samples.

Mechanical analysis	Surface	Subsoil
	%	%
Moisture	1·24	1·09
Stones	<1·0	nil
Coarse sand	8·5	4·8
Fine sand	53·9	49·2
Silt	15·7	16·5
Clay	13·6	14·5
Calcium carbonate	trace	trace
Chemical analysis :		
" Available " K_2O	0·0126	0·0065
" Available " P_2O_5	0·0227	0·0092

The soil is mainly derived from the underlying Keuper Marl, but the surface soil is rather more sandy, due to colluvial material. Drainage in certain areas is somewhat impeded.

Treatments.

From 1924 to 1940 the annual treatments were as follows :

		Basic rates/acre
J=nil		
K=NPK		
L=PK	Nitrogen	60 lb. N
M=NK	Phosphate	48 ,, P_2O_5
N=NP	Potassium	144 ,, K_2O
O=F.Y.M.	20 tons for 3-year period.	

In 1940 the test crop was changed from strawberry to a rotation of vegetables; plots receiving treatment J were given nitrogen only. This series continued until 1949, during which time the plots received the same fertilizer treatments but the basic rates varied according to the requirements of each crop. F.Y.M. was given at 10 tons per acre annually.

From 1950 onwards the treatments remained unchanged; details are given in Table II.

Layout and plot size.

Each sub-plot is 33 ft. by 22 ft. and is separated from neighbouring plots by paths. The plots are arranged in three blocks but unfortunately the arrangement within the blocks is systematic. Reference to the statistical treatment of the data will be made in the section dealing with results.

TABLE II.

Manurial treatments from 1950 onwards.

Treatment	J.	Annual dressings of nitrogen only, as nitro-chalk (15% N) at 3 cwt. per acre applied in spring.
,,	K.	Annual dressings of nitrogen, phosphate and potassium applied each spring as under : Nitro-chalk (15% N)—3 cwt. per acre. Superphosphate (18% P_2O_5)—4 cwt. per acre. Potassium sulphate (48% K_2O)—1 cwt. per acre.
,,	L.	Annual dressings of phosphate and potassium as above.
,,	M.	Annual dressings of nitrogen and potassium as above.
,,	N.	Annual dressings of nitrogen and phosphate as above.
,,	O.	F.Y.M. at the rate of 20 tons per acre ploughed in prior to planting.

Plants and planting distances.

Virus-free runners of the variety Auchincruive Climax were planted on 29th-30th March, 1950, in rows 3 ft. apart and 18 in. between plants, giving 184 plants per plot. The outside plants on each plot were not recorded. For the purpose of records the number of plants were as follows :

A. Buffer plants—70.
B. Sub-sample for fruit quality—12.
C. Plants used for yield and leaf analysis—102.

Management.

In the first year the inorganic manures were applied in April and in each succeeding year in March. They were lightly cultivated into the soil by hand hoeing. The soil between the rows was kept free from weeds by light surface cultivations prior to strawing down. In the first year, blossom trusses were removed and runners were taken off at intervals. During the first year, missing plants were replaced by runners from adjoining plants. Thereafter missing plants were not replaced and all runners were removed.

No sprays were necessary during the first year, but in 1952 and 1953 the plants were sprayed for the control of aphis.

Leaf sampling.

Leaf samples were taken from the centre of the plants, selecting a leaf which was fully expanded but not senescent. One leaf plus petiole was taken from each of fifty plants. During the first year, leaf samples were taken on one date only, 14th September, but in succeeding years they were taken on three occasions : when the first flowers were fully open, when the first formed fruits were ripe, and finally after the fruit had been picked. The samples were dried at 100° C. and analysed for total N, P_2O_5, K_2O, CaO and MgO in the first two seasons and thereafter for total N, P_2O_5 and K_2O. The analytical results are given in Tables VII and VIII.

RESULTS.

Soil.

The effect of treatments on certain soil constituents is shown in Table III. F.Y.M. increased significantly the organic matter status of the soil but differences

Table III.

Effect of manurial treatments on soil constituents. Expressed as percentage of air-dry soil. Samples taken 17.2.50.

	J N	K NPK	L PK	M NK	N NP	O F.Y.M.	S.E. Mean	Sig. diff. P=0·01	Remarks **P=0·01 *P=0·05
Organic C.	0·91	0·97	0·83	0·89	0·90	1·32	0·039	0·175	** O>J, K, L, M, N * K>L
P_2O_5 sol. in 1% citric acid ..	0·008	0·022	0·021	0·007	0·019	0·029	0·0029	0·013	** K, L, O>J, M * N>J, M
P_2O_5 sol. in N/2 acetic acid ..	0·004	0·013	0·012	0·004	0·014	0·020	0·0022	0·010	** O>J, M * K, L, N>J, M
Exchangeable potassium (K) ..	0·007	0·016	0·018	0·017	0·007	0·020	0·00085	0·0038	** O>J, K, N K, L, M>J, N
pH	6·5	6·6	6·7	6·4	6·6	6·9	—	—	—

between the inorganic treatments were not significant at the 1 per cent. level of probability. At the 5 per cent. level, omission of nitrogen lowered the organic matter content.

Omission of phosphate had a significant effect on the available soil phosphate as determined by the solubility in 1 per cent. citric and N/2 acetic acids. The available phosphate under N only and NK treatments was at deficiency level. The highest phosphate level was on plots receiving F.Y.M.

Omission of potassium decreased significantly the exchangeable potassium to deficiency level. The exchangeable potassium on plots receiving F.Y.M. was significantly higher than on plots receiving complete artificials.

Treatments had no significant effect on soil pH.

TABLE IV.

Markings of plots for vigour of plants for the seasons 1950-53. Maximum total of marks for 3 plots=30.

Date	Treatments					
	J N only	K NPK	L PK	M NK	N NP	O F.Y.M.
1950						
May	8	18	9	8	10	22
June	10	20	13	11	11	22
July	10	22	13	16	14	24
1951						
May	15	22	14	22	15	25
June	16	25	16	25	16	28
July	14	28	20	27	13	29
1952						
May	15	28	15	28	14	27
June	15	28	15	30	16	26
July	14	27	14	29	16	25
1953						
May	15	26	14	29	15	24
June	16	27	14	29	17	25
July	14	25	16	27	15	23

Vigour.

Growth was estimated visually at intervals during the growing seasons by awarding marks from one to ten to each plot, according to vigour. Table IV summarizes the results for the years 1950-53. The recording dates correspond approximately with those for leaf sampling. It will be noticed that, apart from the first season when plants on plots without P were slow to establish, treatment effects fall into two groups. Plants receiving NPK, NK and F.Y.M. were vigorous whilst plants receiving N, PK and NP only made poor to moderate growth. The effect of omitting nitrogen was less severe than that of omitting potassium. Plants not receiving phosphate increased in vigour after the first season and maintained their good growth throughout, whilst plants receiving F.Y.M. declined in vigour in the last two seasons.

Leaf symptoms.

1950. Omission of nitrogen resulted in pale green foliage in contrast to the dark green leaves of plants receiving inorganic nitrogen. Leaves of plants receiving F.Y.M. were slightly paler in colour than those of plants receiving NPK. No phosphorus deficiency symptoms developed but plants on plots with P omitted were slow to establish. Slight marginal leaf scorch developed later in the season on plots without K.

1951. Slight to medium marginal leaf scorch developed towards the end of June (second leaf sampling) on plots without K and on those with N only. By the end of July leaf scorch was severe on these plots. Leaves of plants receiving F.Y.M. were paler green than plants on plots receiving inorganic nitrogen. No phosphorus deficiency symptoms developed. The foliage of plants on plots without N showed nitrogen deficiency symptoms. The amount of " June yellows " was only slight.

1952. Transient " June yellows " appeared on most plants this season. Apart from a slightly lower incidence on plots without N, there appeared to be no correlation with treatments. At the time of the second leaf sampling, leaves of plants receiving no potassium showed marginal chlorosis but no scorch. A week later leaf scorch was medium to severe on these plants. Plants receiving no nitrogen showed medium to severe nitrogen deficiency symptoms. No phosphorus deficiency symptoms were apparent on plants without P.

This season a more severe leaf symptom known as " streaky yellows " made its first appearance. The incidence of this symptom together with the final plant stand is given in Table V.

Table V.

Incidence of " streaky yellows " and final plant number from three plots.

	Treatments						Maximum No.
	J N only	K NPK	L PK	M NK	N NP	O F.Y.M.	
Streaky yellows 30/7/52	28	19	13	31	35	25	306
Plant stand	289	297	303	299	299	299	
Streaky yellows 27/7/53	137	115	81	108	132	128	306
Plant stand	263*	291	299	294	269*	289	

* Plant stand partly affected by defective drainage on two plots.

Table VI.

Effect of treatments on the second crop of flowers. Totals from three plots, five plants per plot. 7th October, 1952.

Flowers	J N only	K NPK	L PK	M NK	N NP	O F.Y.M.
Open	170	43	8	32	144	44
Unopened	65	136	72	112	43	99
Total	235	179	80	144	187	143

Towards the end of the season the plants carried a second heavy crop of flowers. A blossom count was made on five plants from each plot. Table VI shows the effect of treatments on the number of open and unopened blossoms.

The number of flowers tended to be high on low-yielding plots without potassium. Omission of nitrogen reduced greatly the number of flowers per plant.

1953. Leaf symptoms were much the same as in the previous year: medium to severe leaf scorch on plots without K, nitrogen deficiency on plots without N, slight N deficiency on F.Y.M. plots, but no phosphorus deficiency symptoms on any plants.

Leaf analyses.

The results for 1950-51 together with tests of significance and remarks are given in Table VII, and for 1952-53 in Table VIII. Figs. 1 and 2 illustrate the changes in leaf nutrient status at three stages, namely: flowering, fruit ripening, and after fruit picking for the fruiting seasons 1951, 1952 and 1953.

1950. Treatments had no significant effect on nitrogen or calcium, the effect on phosphate and magnesium was significant at the 5 per cent. level of probability and the effect on potassium was significant at the 1 per cent. level.

1951. At the flowering stage, treatment effects were significant at the 1 per cent. level on nitrogen, phosphorus and potassium and at the 5 per cent. level on magnesium.

At fruit ripening, treatment effects continued to be significant on nitrogen and potassium but there were no significant differences in phosphorus, magnesium and calcium levels.

After fruit picking, differences in nitrogen and potassium continued at the 1 per cent. level of significance. Differences in the magnesium status became significant at the 1 per cent. level, no doubt due to the very low potassium contents in plants receiving treatments J and N, thus illustrating the antagonism between potassium and magnesium uptake.

1952. At the flowering and fruit ripening stages, treatment effects were significant at the 1 per cent. level for potassium, at the 5 per cent. level for nitrogen but were not significant for phosphorus.

After fruit picking, significant effects at the 1 per cent. level were observed in nitrogen, phosphorus and potassium status.

1953. Differences, significant at the 1 per cent. level, in all three nutrients were observed at flowering. At fruit ripening the significance diminished to the 5 per cent. level for phosphorus and after fruit picking the effect on phosphorus was not significant. Significant effects on nitrogen and potassium continued at the 1 per cent. level.

Yield of fruit.

The crop was picked during a period of three to four weeks, but for convenience and statistical analysis the yield figures have been grouped into four harvests, the groups being comparable over the years.

As noted previously, the layout within the blocks was systematic, but the statistical analysis was carried out as for randomized blocks. Block differences appeared in 1952 only, and it is hoped that the systematic layout did not introduce too serious correlations between the effects of neighbouring treatments.

The analysis of variance between blocks, treatments and harvests was carried

Table VII.

Effect of manurial treatments on the nutrient status of strawberry leaves, var. Climax, 1950-51. Nutrients expressed as percentage of leaf dry matter.

Sampling date	Nutrient	Treatment means						S.E. Mean	Sig. diff. P=0·01 **	Remarks * P=0·05 ** P=0·01
		J N	K NPK	L PK	M NK	N NP	O F.Y.M.			
14.9.50	N	1·76	1·69	1·63	1·71	1·84	1·77	0·051	N.S.	N.S.
	P_2O_5	0·527	0·563	0·579	0·458	0·592	0·579	0·022	—	* J, K, L, N, O>M
	K_2O	1·16	1·69	1·64	1·69	1·09	1·56	0·051	0·226	** K, L, M, O>J, N
	MgO	0·332	0·333	0·349	0·331	0·351	0·402	0·013	—	* O>J, K, L, M, N
	CaO	1·02	1·13	1·22	1·14	1·12	1·17	0·171	N.S.	N.S.
29.5.51	N	3·11	3·19	2·72	3·05	3·20	2·76	0·056	0·251	** J, K, N>L, O
	P_2O_5	0·754	0·834	0·778	0·734	0·857	0·794	0·012	0·052	** N>J, M ; K, O>M
	K_2O	1·75	2·11	2·06	2·00	1·64	1·85	0·052	0·231	** K>J, N, O ; L, M>J, N
	MgO	0·361	0·375	0·353	0·329	0·397	0·411	0·013	—	* O>J, L, M
	CaO	1·03	1·09	1·08	0·94	1·16	1·09	0·057	N.S.	N.S.
19.6.51	N	2·46	2·64	2·05	2·49	2·62	2·25	0·075	0·336	** K, N>L, O
	P_2O_5	0·596	0·600	0·571	0·561	0·641	0·624	0·018	N.S.	N.S.
	K_2O	1·09	1·97	1·90	2·01	1·16	1·95	0·096	0·428	** K, L, M, O>J, N
	MgO	0·428	0·421	0·397	0·396	0·430	0·442	0·140	N.S.	N.S.
	CaO	1·32	1·30	1·37	1·24	1·28	1·13	0·101	N.S.	N.S.
24.7.51	N	2·14	2·12	1·75	2·12	2·10	2·11	0·063	0·284	** J, K, M, N, O>L
	P_2O_5	0·395	0·408	0·447	0·381	0·444	0·427	0·027	N.S.	N.S.
	K_2O	0·57	1·47	1·33	1·59	0·54	1·32	0·091	0·41	** K, L, M, O>J, N
	MgO	0·605	0·495	0·467	0·469	0·650	0·545	0·029	0·130	** N>K, L, M ; J>L, M
	CaO	2·41	2·60	2·41	2·37	2·31	2·36	0·055	N.S.	N.S.

Table VIII.

Effect of manurial treatments on the nutrient status of strawberry leaves, var. Climax, 1952-53. Nutrients expressed as percentage of leaf dry matter.

Sampling date	Nutrient	Treatment means						S.E. Mean 3 plots	Sig. diff. P=0·01 **	Remarks * P=0·05 ** P=0·01
		J N	K NPK	L PK	M NK	N NP	O F.Y.M.			
20.5.52	N	2·99	2·88	2·53	2·85	3·10	2·65	0·10	—	* J, N>L, O ; K, M>L
	P_2O_5	0·786	0·857	0·840	0·760	0·885	0·827	0·026	N.S.	N.S.
	K_2O	1·79	2·35	2·28	2·23	1·76	2·22	0·087	0·39	** K, L, M, O>J, N
9.6.52	N	2·75	2·55	2·07	2·62	2·68	2·44	0·12	—	* J, K, M, N>L
	P_2O_5	0·654	0·652	0·732	0·622	0·659	0·679	0·037	N.S.	N.S.
	K_2O	1·05	1·81	1·79	2·17	1·06	1·65	0·166	0·74	** K, M>J, N ; L>J
14.7.52	N	2·12	1·88	1·57	1·96	2·02	1·80	0·042	0·19	** J>K, L, O ; N>L, O ; K, M, O>L
	P_2O_5	0·493	0·446	0·481	0·385	0·463	0·448	0·015	0·067	** J, L, N>M
	K_2O	0·85	1·64	1·72	1·93	0·85	1·55	0·14	0·64	** K, L, M>J, N
18.5.53	N	3·37	3·18	2·69	2·95	3·35	2·92	0·10	0·45	** J, N>L ; K>L
	P_2O_5	0·81	0·89	1·06	0·76	0·86	0·98	0·020	0·088	** L, O>J, K, M, N ; K>M
	K_2O	1·65	2·19	2·26	2·16	1·80	2·15	0·064	0·29	** K, L, M, O>J, N
29.6.53	N	2·62	2·19	2·19	2·33	2·64	2·30	0·084	0·38	** J, N>K, L
	P_2O_5	0·55	0·61	0·65	0·48	0·67	0·69	0·042	—	* K, L, N, O>M ; O>J
	K_2O	0·98	1·76	1·88	1·80	1·02	1·79	0·13	0·56	** K, L, M, O>J, N
15.7.53	N	2·21	1·97	1·74	1·82	2·23	1·89	0·079	0·35	** N>L, M ; J>L
	P_2O_5	0·41	0·47	0·53	0·46	0·49	0·53	0·089	N.S.	N.S.
	K_2O	0·81	1·48	1·65	1·63	0·76	1·52	0·11	0·49	** K, L, M, O>J, N

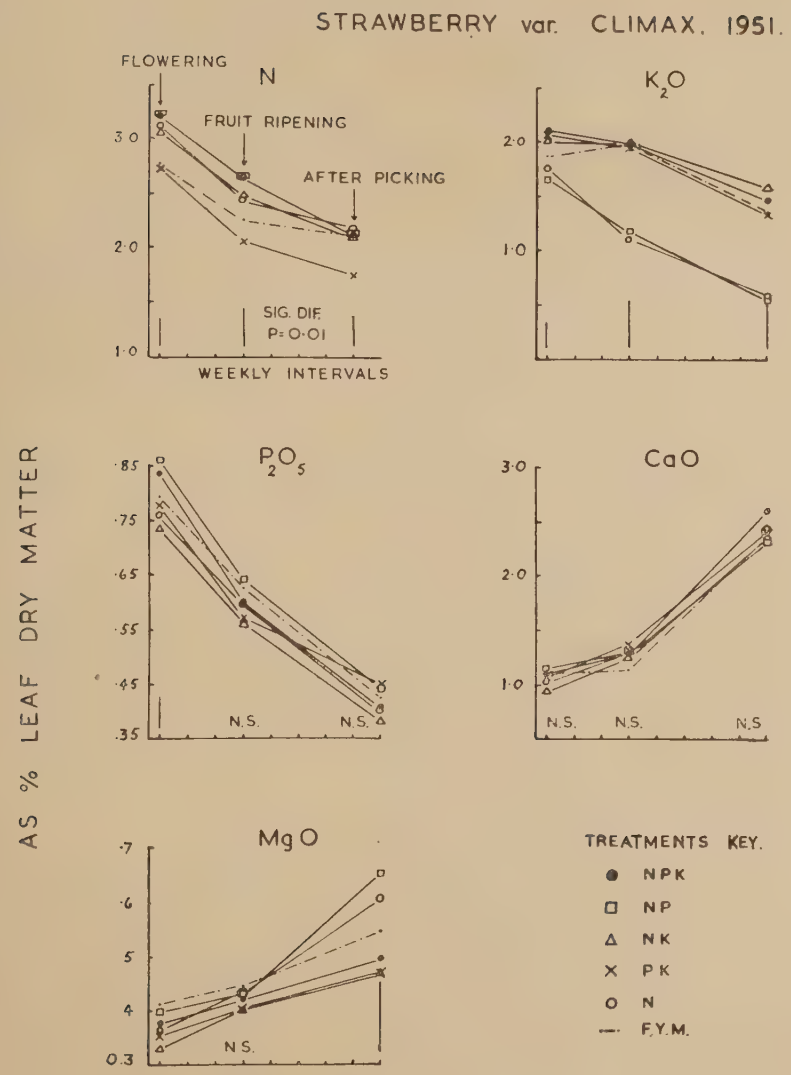

Fig. 1.

The effect of manurial treatments on the leaf nutrient status of strawberry, variety Climax, in the first cropping season.

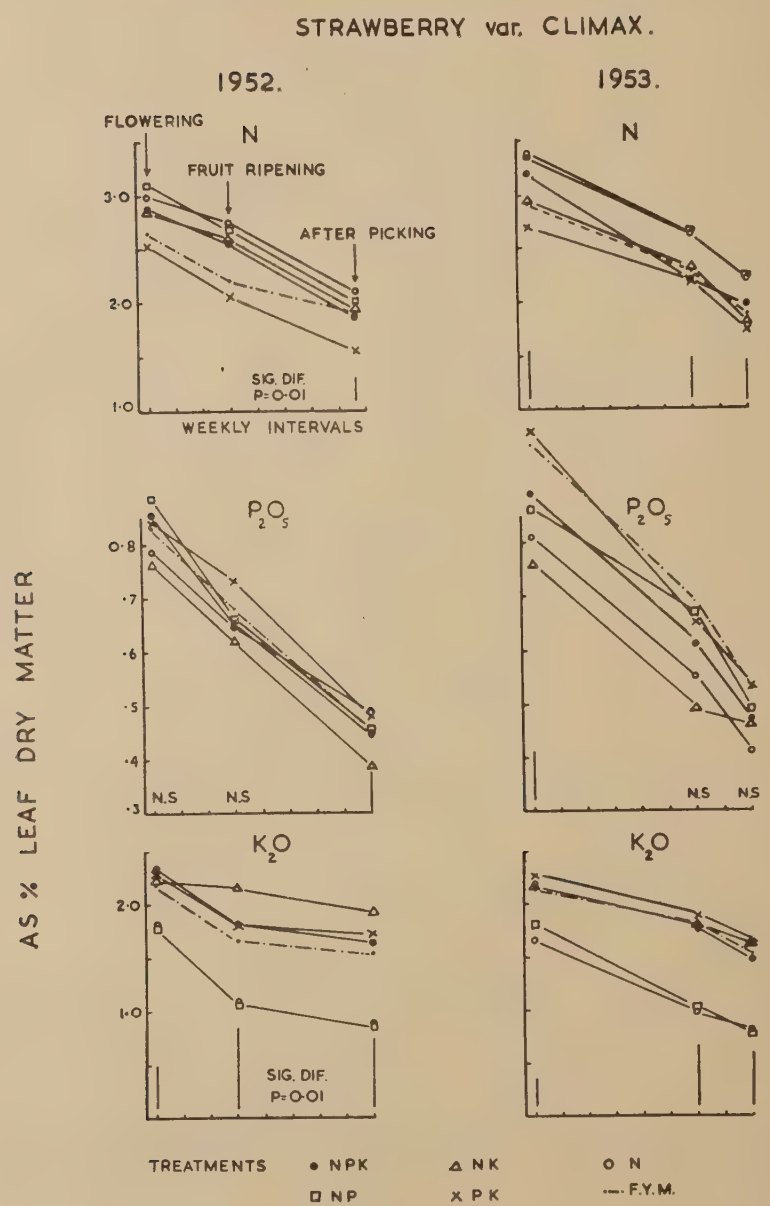

FIG. 2.

Showing the effect of manurial treatments on the changes in leaf nutrient status of strawberry, variety Climax, during the second and third cropping seasons.

out by the method proposed by Pearce (5), section 25. However, the error was not divided into two parts, since significance was clearly established for the harvest × treatment interaction whether or not the division was carried out.

The effect of treatments on total yield and grade I fruit, together with tests of significance, is shown in Table IX.

1951. Treatment effects were significant at the 1 per cent. level of probability and the harvest × treatment interaction at the 0·1 per cent. level.

F.Y.M. and NK treatments induced late cropping, NPK a little later than average and N, PK and NP induced early cropping. (These terms "early" and "late" are only relative.)

1952. Treatment effects were significant at 1 per cent. level and harvest × treatment interaction at the 0·1 per cent. level. Treatments F.Y.M., NK and NPK induced late cropping and N, PK and NP early cropping.

1953. Treatment effects and harvest × treatment interaction were both significant at the 0·1 per cent. level.

Overall effects 1951-53.

An analysis of the results for the whole period shows that the treatments fall into two groups, namely NPK, NK and F.Y.M. > N, NP, PK. The relative yields from F.Y.M. plots in 1952 and 1953 fell by comparison with 1951. Plants receiving NPK, NK and F.Y.M. cropped heavily and late by comparison with plants receiving N only, NP and PK.

The effect of treatments on rate of maturity of fruit is shown in Fig. 3. The graph shows the excess (or otherwise) by which each treatment cropped over average at each harvest. The "expected" figure was calculated on the hypothesis that the same proportion of each treatment cropped at each harvest and "expected" minus "observed" figures are plotted in units of 1 lb. as ordinates. The three years are shown separately. Poor picking weather in 1953 caused the overall first harvest (and consequently its variation) to be rather small.

DISCUSSION.

Differential manuring over a period of nearly thirty years produced marked differences in soil fertility as measured by the chemical determination of organic matter, exchangeable potassium and acid-soluble phosphate. As was expected, plots treated with farmyard manure had a higher organic matter content (approximately 26 per cent.) than plots treated with complete artificials; omission of phosphate and potassium had no significant effect but omission of nitrogen from the inorganic manures reduced the organic matter status (at the 5 per cent. level of probability). It is difficult to assess the relative importance of organic matter in the growth and yield of strawberries at Long Ashton because of the fairly heavy rainfall at this centre. Equally good yields, in quality and quantity, can be obtained by the use of inorganics.

Omission of nitrogen from otherwise complete inorganics reduced vigour during the first season after planting but had no significant effect on the nitrogen status of the leaves as determined in September. However, these plants were not cropped and the reserves in the new crowns were apparently sufficient to maintain adequate nitrogen levels at the expense of new growth. In the second season (first cropping

TABLE IX.

Effect of manurial treatments on grade and yield of fruit in tons per acre (means of three replicates).

	Season	J N only	K NPK	L PK	M NK	N NP	O F.Y.M.	Mean	S.E. Mean	Sig. diff. P 0·01 ** 0·05 *	Remarks
Grade I	1951	4·23	5·43	5·33	5·67	4·51	5·82	5·17	0·296	1·324 0·931	** M, O>J * M, O>N ; K, L>J
	1952	3·23	5·39	4·69	6·06	3·42	5·47	4·71	0·248	1·112	** K, L, M, O>N, J ; M>L * O>L
	1953	2·96	5·29	4·03	5·32	2·82	4·65	4·18	0·210	0·941	** K, L, M, O>N, J ; K, M>L * M>O
Total yield	1951	5·24	7·01	6·31	7·12	5·70	7·77	6·52	0·403	1·806 1·270	** O>N, J ; M>J * M>N ; K>J
	1952	6·89	9·04	7·25	9·19	5·93	8·34	7·77	0·511	2·290 1·610	** M>J, N ; K, O>N * M>L ; K>L, J
	1953	5·73	8·14	6·07	8·37	5·32	7·57	6·87	0·411	1·842 1·295	** K, M, O>N, J ; K, M>L *O>L
Grade I as a % of total yield	1951	80·7	77·5	84·5	79·6	79·1	74·9	79·2			
	1952	46·9	59·6	64·7	65·9	57·7	65·6	60·6			
	1953	51·7	65·0	66·4	63·6	53·0	61·4	60·2			

season) omission of nitrogen not only reduced vigour and yield of fruit but had a highly significant effect on the nitrogen status of the leaf at all sampling dates. This effect continued throughout the life of the crop and leaves showed severe nitrogen deficiency symptoms in the later stages. The average leaf nitrogen values over the years 1951-53 at flowering, fruit ripening and after fruit pick for plants without N (P and K sufficient) were 2·65, 2·10 and 1·69 per cent. dry matter respectively. Plants with these nitrogen values show nitrogen deficiency symptoms and produce

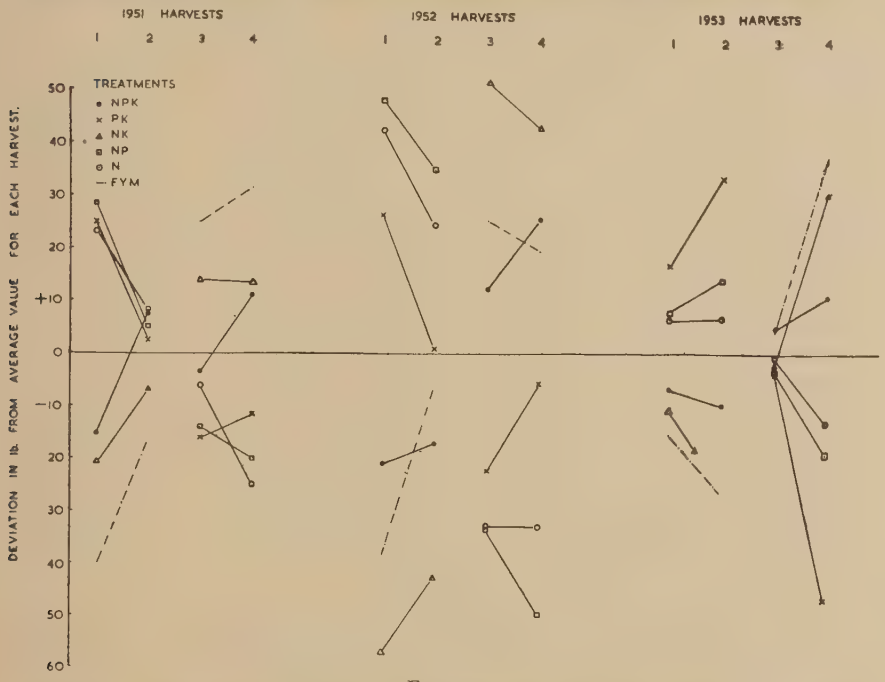

Fig. 3.

Strawberry, variety Climax. Deviation of crop for each treatment from average at each harvest for the seasons 1951-53.

sub-optimum yields of fruit. The corresponding average values for F.Y.M. plants (P and K sufficient) are 2·78, 2·33 and 1·93 per cent. dry matter respectively, and for NPK plants (P and K sufficient) 3·08, 2·46 and 1·99 per cent. Relating these figures to vigour, yield and quality of fruit, it would appear that the nitrogen levels of the F.Y.M. plants were about optimum for this variety of strawberry. The higher levels in the NPK plants produced a little too much vigour without a corresponding increase in yield of fruit.

Omission of phosphate from the manures reduced the available soil phosphate to approximately one-third of the level on NPK plots, a level which was deficient for other crops, yet the strawberry variety Climax was able under these conditions to

obtain sufficient phosphorus for normal growth and optimum yields. The young plants were slow to establish and this was probably related to the significantly lower leaf phosphate at the end of the first season and at the first sampling of the second season. However, at the second and third sampling dates in 1951, treatments had no significant effect on leaf phosphate. The plants by this time were growing vigorously and showed no symptoms of phosphorus deficiency. At the last sampling date in 1952 and the first and second sampling dates in 1953 the leaf phosphate level in plants without P was lower than in NPK plants, but this had no effect on vigour or yield of fruit. All the leaf phosphate values were therefore well above the threshold value (value below which deficiency symptoms appear) and were probably in the region of the optimum for this variety. The threshold value quoted by Lineberry *et al.* (4) for strawberry leaves in June was above 0·45 per cent. Plant leaves containing 0·68 per cent. P_2O_5 showed no deficiency symptoms. This lack of response to the omission of phosphate was surprising in view of the usual recommendations for strawberry manures. However, leaf analysis showed quite clearly that the variety Climax was obtaining adequate amounts of phosphorus from a phosphorus-deficient soil, rather than making normal growth on a low level of leaf phosphorus. This result emphasizes the importance of leaf analysis in the interpretation of manurial trials. Without leaf analysis the inference might have been that the strawberry plant could make normal growth with low amounts of cell phosphorus.

Omission of potassium reduced the available soil potassium to deficiency level. F.Y.M. on the other hand contributed more potassium than did the inorganic manures.

The effect of omitting potassium on plant growth, fruit yield and leaf potassium level was highly significant even in the first season after planting. Vigour was reduced by half as compared with NPK. The effect on the quantity, quality and size of fruit was very marked. The average annual yield of total fruit over three seasons was reduced from eight tons to five and a half tons per acre, and the amount of grade I fruit from five and a half tons to three and a half tons per acre. In addition, as pointed out by Kieser *et al.* (1), omission of potassium produced fruit poor in colour and lacking in full flavour and aroma.

The effect of omission of potassium was reflected in a lower potassium content in the leaf at all stages throughout the duration of the crop. Each season severe leaf scorch developed on plots without K and with N only, about the time of fruit ripening. (At this stage there is a heavy withdrawal of K from the leaves by the fruit.) The average K_2O content at this stage was 1·08 per cent. and 1·04 per cent. K_2O respectively. The average value for NPK plants was 1·85 per cent. K_2O. It would appear from these results that the threshold value for leaf potassium at the time of fruit ripening is in the region of 1·1 per cent. K_2O. Lineberry *et al.* (*loc. cit.*) state that strawberry leaves containing 1·4 per cent. K_2O at this stage of development showed no potassium deficiency symptoms and did not respond to additions of potassium.

Leaf analysis indicates why F.Y.M. is a good manure for strawberries. Apart from any physical effects which it may have on the soil it supplies adequate amounts of potassium with intermediate amounts of nitrogen, conditions which appear to be optimum for good growth and heavy yields of the strawberry variety Climax.

More information on yield and leaf analysis, particularly that provided by factorial NPK experiments, is required before one can establish more accurately the

threshold and optimum leaf nutrient values at different stages in the growth of the strawberry plant. Further work is in progress along these lines at Long Ashton and at other centres.

SUMMARY.

1. The effects of long-term manurial treatments, comparing F.Y.M., complete inorganics and omission of N, P and K respectively, on soil fertility, plant growth, yield of fruit and leaf nutrient status of strawberry variety Climax, are described.

2. Manurial treatments had a significant effect on soil organic carbon, exchangeable potassium and acid-soluble phosphate.

3. Significant effects were produced on plant vigour, and yield and quality of fruit. Omission of potassium had a serious deleterious effect on growth, yield and quality of fruit. Omission of nitrogen reduced growth and yield of fruit without affecting quality. Omission of phosphate had no significant effect on growth, yield or quality of fruit. Complete artificials produced high yields and good quality fruit.

4. Omission of potassium and nitrogen reduced the level of these two nutrients in the leaf below their threshold values and produced severe deficiency symptoms in the leaf. Omission of phosphate reduced the phosphorus content of the leaf at certain stages but the level was sufficient to produce normal growth and high yields of fruit. The strawberry variety Climax appears to be able to obtain sufficient phosphorus for normal growth from a soil low in available phosphate.

5. Plant growth and yield of fruit were related to the levels of nitrogen and potassium in the leaf at the time of flowering and fruiting. The results indicate the value of leaf analysis in manurial experiments with strawberry.

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THE INDUCTION OF SELF-FERTILITY IN TREE FRUITS

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THE knowledge that cross-pollination between varieties of tree fruits is necessary for the production of a crop has removed one of the main difficulties, in modern massed fruitgrowing, caused by self-sterility. But even with this knowledge there still remain advantages in growing self-fertile varieties.

Firstly, owing to the possibility of growing large blocks of one variety without pollinators, the harvesting and cultivation are simpler and more economical. Secondly, as pointed out by Crane and Brown (1937), " since theoretical conclusions indicate that a self-compatible variety is likely to be universally effective on self-incompatibles it might be of considerable practical value ". Thirdly, evidence has shown (Bateman, 1947a, 1947b) that hive bees mainly confine their work to an area of 180 sq. ft., i.e. not much larger than a good-sized fruit tree, and only rarely do they wander during a single forage from this area. This localization has been found by Butler (1943) to be accentuated when few bees are working in the cool conditions often prevailing at the time of fruit blossoming. This would result in self-pollination and a light crop. Evidence that this factor can be very important comes from plums in which there are both self-sterile and self-fertile varieties. Most of the regular croppers such as Victoria, Pershore and Denniston's Superb are self-fertile ; the more erratic croppers even with provision for cross-pollination, such as President and Old Greengage, are self-sterile. From this it would appear that self-fertile varieties of other fruit species might be of advantage to fruitgrowing. The present account describes a method for inducing complete self-fertility, first tested in a species which has a self-sterility system similar to that in fruit trees, and later successfully repeated with cherries.

INDUCING SELF-FERTILITY. BASIS OF THE METHOD.

The genetical control of self-sterility in many species is by a large series of multiple alleles, S1, S2, S3 . . . Sn. The work of Crane and Lawrence (1931) and Crane and Brown (1937) has shown that this is the system at work in *Prunus avium* ; probably there is a modified system, due to polyploidy, in apples and pears. The knowledge that the same system operates in a wide range of species enables us to use a quick-maturing species in pilot experiments and apply the results obtained to the slow-maturing fruit trees.

The alleles S1, S2, etc. operate by controlling pollen-tube growth, each allele conferring a highly specific mating reaction on pollen grains and styles. When the pollen and styles carry the same allele, as with self- and cross-incompatible pollination, pollen-tube growth is stopped short. When the pollen carries a different allele to those in the style, as with compatible pollination, the pollen tubes grow the full length of the style and achieve fertilization.

Physiological experiments (Lewis, 1942) have shown that incompatibility is not due to a negative effect—a lack of some growth substance—but to an active produc-

tion of specific substances in the pollen tube and style which interact to stop the growth of the tube. This gives a clue to the method of producing self-fertile plants.

Experiments on gene mutation in general have shown that spontaneous and induced mutations are usually a change to a less active allele and often to an allele which has lost all its activity. This is why most gene mutations have a deleterious effect.

When the incompatibility gene mutates, a pollen grain containing such a mutant-allele will be compatible even in self-pollination because it will have an allele which is different from those in the style (cf. Lewis, 1948). Thus on selfing there may be a few seeds produced which are the result of **S** gene mutation. Since thousands of pollen grains can be placed on a stigma, self-pollination provides a sieve for selecting out of millions of pollen grains only those which have an **S** mutation.

Thus X-rays give us the means to damage the **S** gene. The stylar sieve of incompatible self-pollination gives the means of selecting out of millions the few **S** genes that have been damaged.

Pilot experiments.

Before starting on large-scale experiments with fruit trees, pilot experiments were made with more amenable material. The species chosen for this was *Oenothera organensis*, a plant with an incompatibility system as in *Prunus avium*, an annual life-cycle enabling results to be obtained quickly, and a large stigma on which much pollen could be applied.

As some of the results with *Oenothera* have already been published (Lewis, 1946, 1948), only a brief summary of the points which concern the methods used to produce self-fertile fruit trees will be given.

1. The most suitable X-ray dose was found to be 500-1,000 r units. This produced 5-68 mutations in a million **S** genes, according to the conditions during irradiation.

2. No effect is obtained by irradiating either mature or immature pollen grains, probably because at this stage the **S** gene has already initiated the necessary synthesis to produce the incompatibility substance in the pollen grain.

3. A higher temperature during irradiation increases the yield of mutations.

4. Out of eighteen **S** mutations induced by X-radiation seven were to an allele which conferred complete self-fertility on the plant and the eleven others were to alleles which made the plants partially self-fertile. The self-fertile plants were in no way inferior in vigour or fertility to the normal ones.

Technique with cherries, apples and pears.

Flower buds were examined by the aceto-carmine method during February and March to determine the stage of meiosis. Branches selected for X-irradiation included some in the resting stage as well as others on which the buds were found to be in the late stages of meiosis. The dosage rate was 110 r units per minute, obtained with 6 m. amps., 75 Kv. and at a target distance of 30 cm. Two different temperatures, 10° and 24° C., were maintained during and one hour after irradiation ; more mutations were produced with the higher temperature when treatments were given to prophase cells (Lewis, 1949).

The pollen developing from treated buds was applied to the styles of untreated

flowers of the same variety or of varieties incompatible with the treated variety. The latter method was adopted wherever possible because it avoids the effect, if any, of inbreeding on vigour. At the same time attempts were made to obtain spontaneous mutants using unirradiated pollen.

The selection of suitable varieties of cherries to be used in the treatments was based not only upon their fruit quality but on their potentiality to give seedlings after incompatible pollination. Examination of the published (Crane and Brown, 1937) and unpublished results of self-pollination showed that incompatibility groups III and V gave five to ten times as many fruits and seeds as the other groups (Lewis, 1948). Thus these groups were selected for treatment in the hope that a higher yield of seedlings with a mutant **S** allele would be obtained. For this reason some varieties such as Turkey Heart and Late Black Bigarreau were used despite their indifferent fruit qualities.

Results.

The results given in Table I are the total of different dosages and treatments with sweet cherries. The mean fruit set of all these treatments and varieties is 1·4 per cent., a value which is approximately 10 times larger than the mean obtained with untreated pollen. Table II gives a summary of the results obtained with apples and pears. The fruit set and seeds obtained after pollination with irradiated pollen is about 3-4 times higher than with untreated pollen. It is probable that apples and pears, being secondary polyploids, would tolerate a much higher dose of X-radiation, and the most profitable dose may be in the region of 2,000-3,000 r rather than 600 r.

Table I.

Fruits and seeds produced in sweet cherries after treating pollen mother cells with X-rays and followed by incompatible pollination.

	Variety used as ♂	Flowers	Fruits	Seeds	% Fruits set
Control	Turkey Heart	2,226	6	6	0·26
	Bigarreau Napoleon	2,969	3	2	0·10
	Emperor Francis	3,459	6	6	0·17
Treated	Turkey Heart Late Black Bigarreau	6,727	135	73	2·0
	Bigarreau Napoleon Emperor Francis	8,145	94	55	1·1
	Hedelfingen Bradbourne Black	7,355	96	42	1·3
	Governor Wood Stark's Gold	1,356	31	15	2·3
	Early Amber	499	5	2	1·0
	Frogmore Early	373	2	1	0·5
	Total treated	24,455	363	188	1·4

The figures are for the totals of all treatments, including X-ray dosages ranging from 90 to 800 r units, different temperatures, 14° and 26° C. during irradiation, and different stages of development ranging from resting stage to metaphase. Note that the pairs of varieties are cross-incompatible, and that the treated variety was used as a pollen parent either on itself or on the other incompatible variety.

Table II.

Fruit and seed production in apples and pears after 600-800 r units and self-pollination.

	Variety	Flowers	Fruits	Seeds	% Fruits set
	Apple				
Control	Cox's Orange Pippin ..	12,680	96	—	0·7
	Ellison's Orange	514	6	—	1·1
	Northern Spy	3,306	25	—	0·7
Treated	Cox's Orange Pippin ..	766	21	39	2·7
	Ellison's Orange	196	4	0	2·1
	Lord Lambourne	606	11	59	1·8
	Northern Spy	540	10	27	1·8
	Pear				
Control	Conference	5,313	41	—	0·7
	Doyenné du Comice	4,364	16	—	0·4
Treated	Conference	320	16	7	5·0
	Doyenné du Comice	Many	55	52	—

One hundred and six cherry trees have been grown from the seeds obtained (of which 42 have been tested). They include 10 plants which produce a small crop of fruit after self-pollination, and four seedlings which are fully self-fertile and correspond to those self-compatible plants of *O. organensis* in which the S allele has lost all its pollen activity. It is of interest that all four of these permanent complete mutations were induced by treatment in the resting stage and not during meiotic division (Lewis and Crowe, 1953).

One fully self-compatible seedling was obtained as a result of a spontaneous mutation out of 10 seedlings tested.

Pear and apple seedlings from mutant seeds have still to be tested.

Breeding from self-fertile seedlings.

Although it is hazardous to generalize from the results obtained in one species and apply them to others, there is usually more justification for doing this when dealing with genetical results which are of a fundamental nature, especially in the present example where the same genetic system of incompatibility is involved in many widely different species.

The results already obtained in cherries repeat those obtained in *Oenothera*. It is therefore permissible to predict that the results of back crossing in cherries will be the same as in *Oenothera*, and if this is so, it is a simple matter to produce a great range of self-fertile descendants from the five self-fertile seedlings (see Table III).

In the first type of cross all the progeny should be self-fertile, in the second type half the progeny should be self-fertile and half self-sterile.

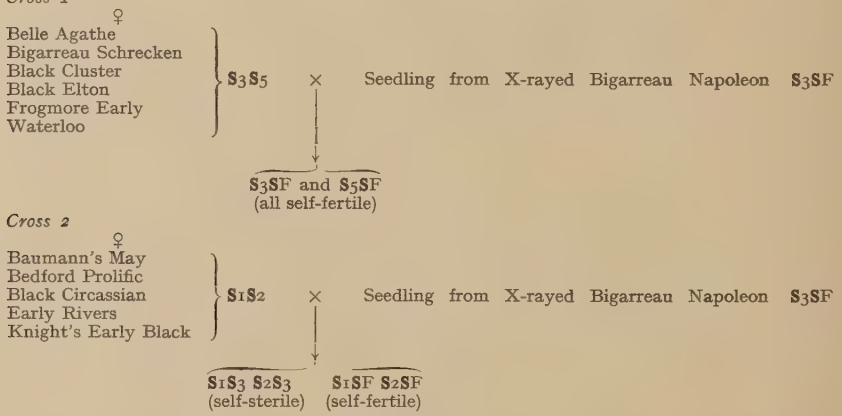
Both these types of crosses have been made in *Oenothera* with the expected results. Some large families of cherry trees from crosses of this kind are now three years old. When they reach the fruiting stage they will provide a range from which to select those seedlings combining self-fertility with other desirable characters.

The vigour of cherry trees is not strikingly affected by a single generation of inbreeding but, on the other hand, after two generations of selfing, seedlings are

perceptibly smaller than outcrossed families of the same age. This reduction in vigour, seemingly a disadvantage, may in fact be useful in the long run as a means of obtaining less vigorous varieties and dwarfing rootstocks on which to grow some of the good but over-luxuriant existing varieties.

TABLE III.

Two crossing methods used to obtain large families of self-fertile cherry seedlings.



Of the original self-fertile seedlings, one is worthy of particular mention. First impressions suggest that it is a very early ripening cherry comparing favourably in this respect with Guigne d'Annonay, one of the earliest existing varieties. The fruits are purplish-black, shiny and heart-shaped with tender juicy flesh, and appear to be of good size and flavour. If the early promise of this seedling is fully realized in more extensive tests it should prove a useful addition to the really early varieties.

While self-fertility in fruit trees is itself an asset, it also offers advantages by providing a choice of breeding methods. It may be easier to obtain by self-pollination, as opposed to the hitherto enforced cross-pollination, many of the commercially desirable features which appear to be controlled by recessive genes. For instance, the seedling just described was obtained by self-pollination and is an unusually early cherry. This fact may be due to a rare state of homozygosity at one or more loci, seldom encountered by outcrossing but much more likely to be recovered by inbreeding. Artificially induced self-fertility in a normally outcrossing species can facilitate the recovery of useful recessive genes in a homozygous state and, by so doing, can release latent variability within the species and thus increase the overall range from which to select new varieties.

SUMMARY.

1. A method of producing self-fertile varieties of fruit trees is described. X-radiation is used to damage the incompatibility (**S**) gene, and the sieving mechanism of incompatibility is used to select, out of millions, the few **S** genes which have been damaged.

2. Pilot experiments with the self-sterile *Oenothera organensis* provided a technique which has been successfully applied to sweet cherries, and to apples and pears. X-rays, given to pollen mother cells of sweet cherries, increase the production of fruit and seed, after incompatible pollination, approximately tenfold.

3. The most suitable stage of development for X-ray treatment in cherries is the resting stage, for only then are permanent complete mutants produced. The best dosage is about 800 r units for cherries.

4. Ten per cent. of the progeny obtained after X-radiation and incompatible pollination in cherries are fully self-fertile.

5. In *Oenothera*, crosses of these self-fertile plants with self-steriles have, according to the cross, given either a half or all self-fertile progeny. Thus large families of self-fertile seedlings can be produced giving an adequate range from which to select self-fertile plants of high quality.

6. The advantage of inbreeding for releasing new variation such as extreme earliness, which has been found among the self-fertile cherry seedlings, is discussed. The loss of vigour due to the continued inbreeding which is possible with self-fertility, may be a source of dwarf varieties and rootstocks.

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We have pleasure in thanking Mr. M. B. Crane and Mr. A. G. Brown for the use of their trees of the varieties used in these experiments.

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EXPERIMENTS ON THE CONTROL OF BROWN ROT OF APPLES AND PLUMS

IV. A SUPPLEMENTARY NOTE ON WINTER SPRAYING

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An earlier paper in this series (Byrde, 1952a) dealt with the possibility of controlling fruit infection by the brown rot fungi, *Sclerotinia fructigena* Aderh. and Ruhl. and *Sclerotinia laxa* Aderh. and Ruhl., by means of a winter eradicant fungicide. It was shown that, while such applications largely inhibited the sporulation of overwintered mummified fruits, there was no significant reduction in the subsequent infection of the developing apple and plum crop. It was suggested that this was probably due to the rapid build-up of the small inoculum which inevitably survived the eradicant treatment. This hypothesis is supported by the data presented below.

Experimental.

Site.

The site used for this experiment was a wedge-shaped area, with its apex pointing north, located near the south-west corner of the Long Ashton plantations, and flanked on the east and south-east by cider trees. To the west and south-west—the direction of the prevailing winds—only a row of damsons against the boundary fence separated the area from open pasture land. On this site, fourteen sixteen-year-old bush apple trees of the variety Laxton's Superb stood at 20 ft. apart in grass, in two rows. The more easterly row, running the length of the site, comprised nine trees ; the short westerly row comprised five trees.

The four trees in the northerly apex of the area received a standard tar-oil wash in the winters of 1951-52 and 1952-53, and served as controls. The winter wash applied to the remaining ten trees incorporated pentachlorophenol as an eradicant fungicide.

Spray materials.

The standard tar-oil wash was formulated by emulsifying 3½ gal. tar-oil with an equal quantity of 5 per cent. sulphite lye ; the resulting stock emulsion was diluted to 100 gal. for use. When it was required to incorporate pentachlorophenol in the oil, a 20 per cent. solution (*w/v*) of the material in oil was prepared by gentle heating ; after cooling, the oily solution was emulsified in the usual way. The final concentrations of pentachlorophenol and tar-oil were 0·7 per cent. and 3·5 per cent. respectively.

Spray application.

Sprays were applied on 12th February, 1952, and on 25th February, 1953, by means of a conventional power spraying outfit, at a rate of approximately 5 gal. per

tree. Triple-nozzle lances, with $\frac{4}{64}$ in. discs, were used, at a pump pressure of 400 lb./sq. in. At the time of spraying, all mummified fruits were removed from nearby apple and damson trees. Both plots subsequently received a normal spray programme each season.

Estimation of results.

To assess the effect of the winter sprays on the sporulation of overwintered mummified apples, a random selection of twenty such fruits was brought into the laboratory in July, and the degree of sporulation of each fruit estimated on an arbitrary scale ranging from 0 (none) to 4 (heavy). From these records, a mean sporulation index for the treatment was calculated.

To examine the spread of the disease on the developing fruit crop, a single wound of standard size was made in the skin of each of five apples per tree at intervals of approximately five days from 5th August, using the wounding instrument described elsewhere (Byrde, 1952b). The proportion of these wounds showing infection by *S. fructigena* was recorded after ten days, ignoring fallen fruits, and the apples allowed to remain on the trees. Such a method simulated natural infection conditions as closely as possible, whilst ensuring a regular occurrence of wounds for infection.

Results.

The apple Laxton's Superb is commonly a biennial bearer, and most of the trees on the experimental site cropped heavily in 1951 and 1953, but only lightly in 1952. Numerous mummified apples were present on the trees in the spring of 1952, but only a small number (one to six per tree) in the spring of 1953. It was therefore convenient to record the effects of the spray on the sporulation of overwintered mummified fruits in 1952. The spread of infection on the developing crop was assessed in 1953 on the eleven trees (seven pentachlorophenol-treated and four controls) which bore a heavy crop that year.

Inhibition of sporulation of mummified apples.

Sporulation of mummified apples, recorded on 11th July, 1952, is summarized in Table I.

Table I.

Sporulation of mummified apples: July, 1952.

Treatment	Sporulation index
Pentachlorophenol (0·7%) in tar-oil (3·5%)	0·35
Tar-oil (3·5%) only	2·42
Least significant difference (P=0·05)	0·59

The addition of the pentachlorophenol to the winter wash resulted in a marked inhibition of sporulation.

Spread of infection in the developing crop.

Table II lists, for each treatment, the aggregate figures to date of wounds showing brown rot infection, together with the probability (P) that these figures differ significantly from each other (2×2 contingency chi-square analysis).

TABLE II.

Proportion of wounds showing brown rot infection : aggregate figures.

Date of wounding	Date of assessment	Aggregate infection expressed as proportion of wounds to date		P
		Control	Pentachlorophenol	
5th August	15th August	0/13 (0%)	0/30 (0%)	—
10th August	19th August	3/27 (11%)	3/62 (5%)	>0·05
15th August	24th August	10/47 (21%)	4/97 (4%)	0·001–0·01
19th August	31st August	13/64 (20%)	9/130 (7%)	0·01–0·02
24th August	4th September	13/81 (16%)	11/162 (7%)	0·02–0·05
31st August	9th September	20/101 (19%)	21/189 (11%)	>0·05
4th September	14th September	28/116 (24%)	42/222 (19%)	>0·05
9th September	18th September	34/134 (25%)	54/257 (21%)	>0·05
14th September	23rd September	44/154 (29%)	70/291 (24%)	>0·05
18th September	28th September	55/168 (33%)	96/325 (30%)	>0·05
23rd September	3rd October	57/184 (31%)	107/358 (31%)	>0·05
28th September	8th October	62/198 (31%)	118/384 (31%)	>0·05

DISCUSSION.

The data presented above show that, in late August, 1953, there was significantly less brown rot infection of wounds on trees which had previously received a tar-oil winter wash incorporating a pentachlorophenol eradicant fungicide than on trees receiving only the standard tar-oil emulsion. This difference, however, steadily diminished and, by 9th September, was no longer significant. At the conclusion of the experiment, early in October, the figures for the two treatments were identical.

Clearly, the critical stage in the outbreak of infection in the pentachlorophenol-treated plot was reached some three weeks after the artificial wounding began. At this stage, it might be expected that the few infections which had developed on the current season's fruit would be contributing a spore inoculum substantially greater than that arising from the overwintered mummified fruits, thus offsetting the effect of the winter fungicide (Byrde, 1952a).

The validity of this reasoning rests on the assumption that the infections developing in the treated plot arose from inoculum within that area, and not from inoculum brought in from outside by wind or insects. The lay-out had been carefully designed with a view to minimizing such external interference, and any randomized design had been rejected on this account. Wilson (1950, pp. 568-9), faced with a similar problem, suggested the use of large square plots, taking records only from the centre trees, or, alternatively, the use of nine-tree plots on the windward side of an orchard adjacent to an open field. A modification of the latter suggestion was adopted for this trial.

Since it has been shown (Wilson and Baker, 1946) that the probability of infection by *Sclerotinia* spores decreases as a function of the distance from the source of inoculum, the nearby control plot represented a greater danger to the treated plot than scattered infections in other leeward parts of the plantations. Any spread of infection from the control to the pentachlorophenol-treated plot, however, should be reflected in an increased infection level in those treated trees adjacent to the control plot, by comparison with those remote from it.

In Table III, the aggregate data on 4th September, 1953—during the critical stage in the build-up of infection in the treated plot—have been analysed in this way, and they show no tendency for such spread. There is thus no reason to doubt the validity of the experiment.

Table III.

Aggregate infection data : 4th September, 1953.

Treatment	Tree nos.	Percentage of wounds infected	Remarks
Tar-oil only (Control)	1–4	16·0	—
Pentachlorophenol in tar-oil ..	5, 6, 11	5·9	Adjacent to Control plot
Pentachlorophenol in tar-oil ..	7–10	7·4	Remote from Control plot

It is also significant that the study of hourly wind records* shows a complete absence of winds between north-west and north-east from 11th August to 5th September inclusive.

The results therefore confirm the opinions expressed in an earlier paper (Byrde, 1952a), namely that winter eradicant spraying against brown rot of apples is generally of little ultimate value in reducing subsequent infection of the developing crop because of the ability of the pathogen to build up rapidly from the small level of inoculum which inevitably survives the fungicide treatment.

SUMMARY.

Winter application of 0·7 per cent. pentachlorophenol, formulated in 3·5 per cent. tar-oil emulsion, to Laxton's Superb apples, was followed by a significant reduction in the infection of wounds by brown rot (*Sclerotinia fructigena*) during August. Subsequently, the rapid build-up of the disease offset the effects of the eradicant fungicidal treatment.

ACKNOWLEDGMENTS.

Acknowledgment is made to Miss M. Marlow and Miss R. Milnes-Walker for help in recording, and to Mr. C. W. Harper, who carried out the spray application.

* Kindly supplied by Mr. G. E. Clothier.

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STUDIES IN THE DEVELOPMENT OF THE STRAWBERRY

II. STOLON PRODUCTION BY FIRST-YEAR PLANTS IN 1952

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A PREVIOUS paper (Robertson and Wood, 1954) reported a study of flower-bud formation in runner plants of the strawberry varieties Sir Joseph Paxton, Royal Sovereign and Auchincruive Climax. Information now given on stolon production was obtained mainly from the small field experiment then described, in which runners formed at known times in 1951 were planted out in the following spring, some later being de-blossomed and others allowed to flower and fruit. The new runners produced were allowed to root undisturbed but were not pegged down.

OBSERVATIONS.

Every leaf of a strawberry plant subtends an axillary bud comprising a growing apex and one or more leaf initials, the latter varying in number with the position of the bud on the crown axis. The first stolons in spring develop from young buds, containing only one or two leaf initials. In crowns with terminal inflorescences, they arise from the oldest axillary buds within the " adjacent " bud, i.e. the bud immediately below the inflorescence, which serves to extend the crown axis (Robertson and Wood, 1954). The typical spring development of this bud is shown in Fig. 1 ; as crown extension proceeds, from 6 to 12 successively formed buds along the extension axis may develop into stolons. In vegetative crowns the first stolons arise in the axils of the second or third youngest leaves visible in the field.

The entire bud, forming the stolon, emerges by rapid growth of the first or basal internode, the leaf initials and stem apex being carried forward at the tip. Growth continues until the first node is several inches from the mother plant, after which the apex is carried further by elongation of the second internode. Thus the stolon is lateral in origin from the mother plant, and morphologically an elongated branch (Fig. 2). The initials at the first and second nodes form rudimentary leaves, with prominent stipules and vestigial laminae or none. Immediately beyond the second node, and enclosed at first by the stipules of the rudimentary leaf, are produced several closely-placed initials which form the leaf rosette of the first runner plant. Root initials develop at the base of the second node, usually emerging all round the circumference of the stolon and growing downwards.

The axillary bud at the second node, i.e. at the base of the runner, usually forms a " continuation " stolon, extending the runner series, and often grows out before the first runner has rooted. Similar stolons arise from leaf axils of the runner itself, but mainly early in the season ; as many as eight continuation stolons were counted in June runners, whereas runners formed after mid-August seldom produced more than one. The axillary bud at the first node of the primary stolon may remain dormant but, early in the season, or if the distal portion of the stolon is damaged, it may itself form a stolon, usually thinner and producing weaker runners than those of the main series.

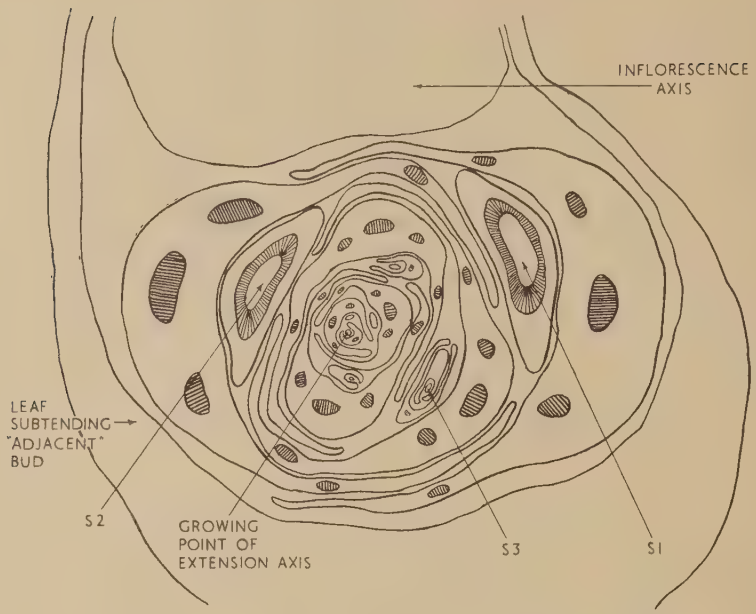

FIG. 1.
Cross section showing the typical spring development of an " adjacent " bud (from var. Royal Sovereign). S1–S3=stolons in order of formation.

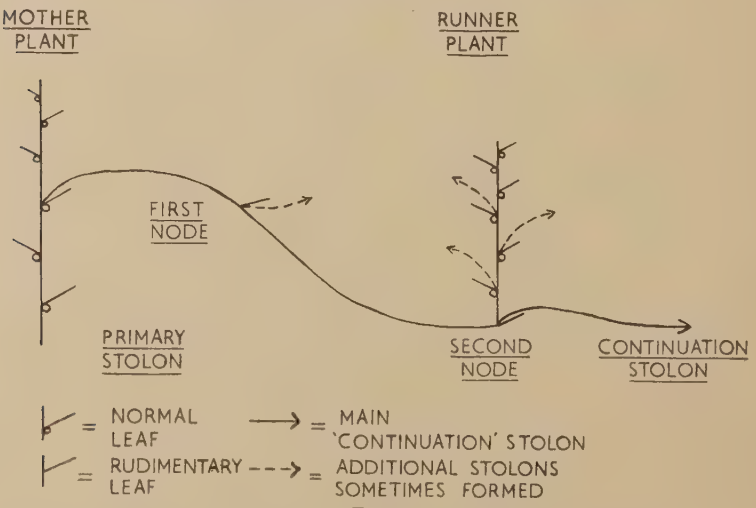

FIG. 2.
Diagram showing the development of a primary stolon and runner plant.

TABLE I.

*The effect of removal of inflorescences on the production of primary stolons.**

Variety	Treatment	No. of plants	Average number of primary stolons per plant by the end of—			
			May	June	July	August
Paxton	De-blossomed	7	0·3	2·7	7·3	10·7
	Control	7	0·3	1·8	5·5	9·2
Royal Sovereign (M.48) ..	De-blossomed	15	1·6	5·2	14·5	19·0
	Control	15	1·9	4·0	9·1	15·5
Royal Sovereign (1/1) ..	De-blossomed	15	1·6	5·1	12·7	21·5
	Control	15	1·6	3·6	10·2	17·1
Climax	De-blossomed	9	0·9	3·4	8·2	13·9
	Control	9	0·9	2·8	6·4	11·6

* Stolons growing directly from the mother plant.

Owing possibly to the checking of the older plants at transplanting, the experiment showed no differences in stolon production between plants rooted at different times of the previous year. Such differences were found in North America by Davis (1925) and Darrow (1929), early-rooted plants forming the most stolons and runners. Primary stolon production in the present experiment was, however, stimulated by de-blossoming (Table I), the treated plants forming extra stolons both from main and secondary (branch) crowns. The last primary stolons of all varieties appeared in early September, but continuation stolons were formed till late October. Overwintered crowns produced stolons mainly in May and June and spring-formed secondary crowns mainly from June to August. The latter, though very variable in number between individuals, averaged between 3 and 4 per plant in all varieties.

By late August the first-formed primary stolons had given rise to the longest series of runners, and they retained their lead throughout the autumn. Data on this and other observations are shown in Table II.

TABLE II.

Production of primary stolons and runner plants.

	Paxton	Royal Sovereign (M.48)	Royal Sovereign (1/1)	Climax
Stolon growth observed microscopically ..	mid-April	early April	early April	mid-April
Stolons visible in field. (Date in 1952)	23/5	28/4	28/4	16/5
Records on 31st August :				
Stolons per plant from main crowns (all plants)	6·0	10·3	10·2	7·5
Stolons per plant from secondary crowns (all plants)	3·9	6·9	9·1	5·2
Runners per plant from first 3 stolons	11·6	54·0	42·9	32·5
Runners per plant from first stolon	6·2	22·7	18·3	19·1

DISCUSSION.

This work, which was subsidiary to the investigation of flower-bud initiation and development previously reported, showed that strawberry varieties differ in the number of stolons their individual plants produce when growing freely. On the total production of primary and continuation stolons depends the yield of runners obtainable from a single mother plant, and it appears that a variety like Royal Sovereign, with many primary stolons, also produces many continuation stolons from its earliest runners ; but this activity soon declines after early summer. Early establishment, therefore, with encouragement of forward growth in spring, would seem desirable to secure maximum propagation. De-blossoming, at least of spring-planted runners, increases the production of primary stolons, a fact confirming its known value in runner-bed management (Rogers, King and Massee, 1939).

SUMMARY.

1. Runners of Sir Joseph Paxton, Royal Sovereign and Auchincruive Climax, planted near Dundee in spring, 1952, showed emerging stolons by the fourth week of May, by late April and by the third week of May respectively.

2. Overwintered crowns produced stolons mainly in May and June, and spring-formed secondary crowns mainly from June to August.

3. De-blossoming increased the production of primary stolons.

4. Early-formed primary stolons produced the longest runner series.

5. The origin and formation of stolons is briefly described.

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REVIEWS

RUSSIAN COMFREY. By L. D. Hills. (London: Faber & Faber. 1953. Pp. 167, illus. Price 15s.)

Symphytum peregrinum and other *Symphytum* spp., their history, cultivation and possibilities in connection with composting, and as fodder. An agricultural crop of interest to the gardener.

D.A.

SOUTH INDIAN HORTICULTURE. South Indian Horticultural Association. Vol. 1, No. 1. (Coimbatore, S. India. 1953. Pp. 32, illus. Price Rs. 5 in India and Rs. 6 abroad.)

The South Indian Horticultural Association was formed in 1952 with the main aim of publishing a horticultural miscellany and has now issued the first number of its illustrated quarterly, "South Indian Horticulture". The new journal will publish review articles by Coimbatore students on practical problems, as well as research and popular articles, and will contain an information column for readers' queries.

J.D.

THE FRUIT YEAR BOOK. 1954. Pp. 116, illus.
THE LILY YEAR BOOK. 1954. Pp. 144, illus.
THE RHODODENDRON AND CAMELLIA YEAR BOOK. 1954. Pp. 162, illus.
THE DAFFODIL AND TULIP YEAR BOOK. 1954. Pp. 165, illus.
The Royal Horticultural Society. (London. October and November, 1953. Price 10s. each.)

Anyone who frequents the Royal Horticultural Society's Shows in London, either at the Society's halls or at Chelsea, will realize how wide are the interests for which it caters. Nevertheless, amongst its numerous Fellows there are naturally many who take a special interest in one or other particular branch of horticulture. For each group there are special Shows, discussions and expeditions, and several groups each produce a Year Book, four of which are listed above.

These books publish papers and describe events of particular interest to those who specialize in one or other subject. The Fruit Year Book has been reviewed annually in this journal, and that now before us is the seventh. It is dedicated to Mr. Norman H. Grubb, veteran pomologist at East Malling, an active member of the Fruit Group since its inception. Like its predecessors, it contains many articles of interest to amateur fruitgrowers, ranging from a description of the development of the model amateur fruit gardens at Wisley to an account of a lecture on the home preservation of fruit. This year there are also reprinted therein several papers of general interest read at the Thirteenth International Horticultural Congress in London in the autumn, 1952.

The Lily Year Book opens with a tribute to the late Walter Bentley, "one of the great amateur gardeners of our day". It contains articles on lilies from overseas, and the inclusion of the discussions of the Lily Group will be of particular interest to those who could not be there.

It is natural that the Rhododendron and Camellia Year Book should open with a tribute to the late Lord Aberconway and a description of the gardens at Bodnant, because his achievements in the field of rhododendron growing " certainly equal those of any of the great growers of the century ". A progress report on the collection of rhododendron species in Windsor Great Park is also of much interest. Articles on camellias and azaleas are included.

The last of the four, the Daffodil and Tulip Year Book, is, perhaps, the most welcome of the flower books to this reviewer, who loves spring flowers rather specially, though possibly " Common Mistakes in Growing Daffodils " is more in his line than some of the more erudite contributions.

All these four Year Books are packed with good things, and we only wish space would allow us to describe them more fully. As it is, we can only recommend the enthusiast who has not already done so to join the Society, seek out his particular group and become a member of it without delay—he will not regret it.

Finally, we would note with satisfaction that the Fruit Year Book at any rate will cost you five shillings less than a year ago.

T.N.H.

GROWING FRUIT AND VEGETABLE CROPS. By T. J. Talbert. (London : Henry Kimpton. 1953. Pp. 350, illus. Price 35s.)

Since up-to-date horticultural textbooks for students are not numerous, any new book in this category deserves special attention. Talbert covers both fruit and vegetable growing in 340 pages ; each chapter consists of about 10 pages and deals with roughly one fruit or one group of vegetables. The information given under each heading is necessarily brief, almost in note form, and some readers may consider that many important matters are omitted. Thus in the improvement of plants there is no mention of the use that is made of hybrid vigour in breeding sweet corn, tomatoes, etc. ; in the chapters on pome fruits there is no reference to manurial needs ; and deficiencies of trace elements are not mentioned as affecting any crop. In spite of these criticisms, this book will obviously prove most valuable to students in Missouri and some other parts of the States and save much note-taking during lectures. The aim to present fundamentals rather than practices has not been sufficiently achieved to assist students outside the States except to give them an impression of culture methods in North America. The chapter on the use of *Rosa multiflora* as a stock-proof fence that needs little routine care merits attention, and this plant may be worthy of trial in other countries. The book is attractively produced and well illustrated, though the lack of a bibliography is a serious omission in a textbook of this nature.

H.B.S.M.

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1. The **Journal of Horticultural Science** is an official organ of the Horticultural and Agricultural Research Station, Long Ashton, Bristol, and the Horticultural Research Station, East Malling, Kent.

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3. Authors of papers containing extensive **numerical observations** should consult the recommendations of the British Association Committee on Biological Measurements, 1927, obtainable from Burlington House, London, W.1. Price 6d. Arrangements have been made whereby original data too extensive for complete publication may be deposited at the British Museum (Natural History), London, S.W.7, or with the Royal Society of Edinburgh, 22 George Street, and thus be available for consultation by other workers. Full bibliographical reference to the publication in which the results are summarized must be supplied with the data.

4. Each paper must conclude with a concise and critically correct **summary** of its actual content. It should contain any new or verified constants as well as any other critical data of permanent value but not tables or graphs. Any organism mentioned should be given its scientific name.

5. Where a paper is of a highly technical nature it should be preceded by a brief **synopsis**, in which its contents are simply and clearly stated for the benefit of non-technical readers.

6. **References to literature** may be by numbers (in brackets) in the text corresponding to a numbered list at the end of the paper or by the Harvard system (author's name and date of publication). By either method, the papers cited should be listed alphabetically according to authors' names, followed by the date of publication. The title of the paper should next be given in full, followed by contracted, but strictly intelligible, title of source of publication, the volume and page numbers. Authors are responsible for the accuracy of their lists of references and should check them carefully in both typescript and proof.

7. The **scientific names** given in the "List of Common British Plant Diseases", published by the British Mycological Society (Cambridge University Press, 1944) and "Common Names of British Insect and other Pests", published by the Association of Applied Biologists (The Mendip Press Ltd., Bath, 1947) must be employed.

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